PRINCIPLES

OF

WARMING AND VENTILATING

PUBLIC BUILDINGS,

DWELLING-HOUSES, MANUFACTORIES, HOSPITALS,

HOT-HOUSES, CONSERVATORIES, &c.;

AND OF CONSTRUCTING

FIRE-PLACES, BOILERS, STEAM APPARATUS, GRATES, AND DRYING ROOMS;

WITH

ILLUSTRATIONS

EXPERIMENTAL, SCIENTIFIC, AND PRACTICAL.

TO WHICH ARE ADDED,

REMARKS ON THE NATURE OF HEAT AND LIGHT;

AND

VARIOUS TABLES USEFUL IN THE APPLICATION OF HEAT.

SECOND EDITION, IMPROVED,

WITH NINE PLATES AND SEVERAL WOOD CUTS.

By THOMAS TREDGOLD,

CIVIL ENGINEER;

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; AUTHOR OF "ELEMENTARY PRINCIPLES OF CARPENTRY;" AN "ESSAY ON CAST IRON," &c. &c.

"We bring some new materials, and what's old
New cast with care, and in no borrow'd mould."—*Young.*

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1824.

TO

THOMAS YOUNG, M.D. F.R.S.

ETC. ETC. ETC.

A MAN EQUALLY DISTINGUISHED

FOR HIS ORIGINAL VIEWS IN NATURAL PHILOSOPHY,

AND FOR HIS PROFOUND RESEARCHES IN EVERY DEPARTMENT OF

MEDICAL AND MECHANICAL SCIENCE,

THIS WORK,

ON HEAT AND VENTILATION,

IS INSCRIBED BY

THE AUTHOR.

ADVERTISEMENT.

A NEW impression of this work being required, I have carefully examined and corrected it, and made additions in various parts of the volume. The principle ones consist of—an investigation and rules for the area of safety valves and main-pipes;—an investigation of the area of surface a boiler should expose to the fire to produce a given supply of steam in a given time;—some additional experiments on the moisture absorbed by different bodies;—a new table of the expansion of air, &c. in which the temperature 60° is made the standard;—a new table of the expansive force, weight, and bulk of steam at different temperatures, from 32° to 310°;—an inquiry concerning the alteration of the composition of atmospheric air by respiration;—and a letter, with which I have been favoured from Dr. Pearson, on an institution for attaining the advantage of equal temperature for invalids.

PREFACE.

In the plan of a course of study, formed for my own use, the principles of managing heat formed one part, and one of considerable importance. Accidental circumstances made it necessary to still further extend the inquiries, which, in the first instance, were to embrace those parts only that are essential to a Civil Engineer; and, I found so little of this branch of knowledge reduced to a state fitted for use in practice, that it was necessary to collect and arrange a new outline of the subject. The outline so collected has been gradually corrected and improved, and, as far as it was applicable, forms the basis of this work. But, since there are few subjects of a practical nature which are of greater or more universal interest, I thought it best to suppress the technical forms of science as much as possible; and where it was not easy to avoid them with-

out either a sacrifice of generality, or giving rules without the reasoning on which they were formed, I have added them in notes, so that they may be consulted or not at the reader's pleasure.

In treating a subject on which there are many preconceived opinions, it was necessary to assign, in the fullest manner, the principles and observations on which my own views are grounded; and which direct my practice, while I have freely, and I trust fairly, canvassed the views of others.

The work is divided into twelve chapters.

The first chapter treats of the advantages and disadvantages of different methods of distributing heat. These, after excluding those which injure the quality of the air, reduce to four: that is, by open fires, by steam, by the cockle, and by fluid stoves with a surface of a limited temperature.

The second chapter is on fuel, and its effect in generating heat; with remarks on the qualities of different varieties of coal, their compo-

sition, and the management which a knowledge of their component parts indicates to be proper for each kind. Other kinds of fuel, as wood, peat, charcoal, coke, &c. are in like manner considered, and data collected from the best experiments. As an introduction to the chapter, the means of measuring the effect of a fuel for different purposes, is pointed out.

The third chapter treats of the effect of steam in distributing heat, and the quantity of fuel that will produce a given effect in warming rooms, &c. In this chapter, the laws of cooling are given in a form adapted for practice; the data for applying them having been ascertained by original experiments, and also the ratio of effect of different surfaces: from whence practical rules of easy application are established, for proportioning the surface of steam-pipe, and the quantity of fuel to supply a given surface of pipe.

The fourth chapter is on ventilation, and the causes of loss of heat. The quantity of ventilation necessary to preserve the air of rooms

pure and fit for respiration is estimated; and the means of procuring it are shewn. The ventilation and loss of heat in hot-houses are also investigated so, I trust, as to remove many erroneous notions respecting the circumstances which occasion a greater or less loss of heat. The ventilation of hospitals, infirmaries, &c. is also considered, and the causes which render common modes ineffectual are shewn.

In the fifth chapter, the construction and proportions of boilers for generating steam, their fire-places and apparatus, is treated of; and the various circumstances which tend to lessen the consumption of fuel, to reduce the quantity of smoke, and to render the whole of the mechanism simple, safe, and effective, are investigated.

The sixth chapter is appropriated to describing the apparatus for distributing steam; where the form, proportions, surface, connexion, &c. of mains, pipes, and vessels, are considered; and also the mode of confining heat in mains or conducting pipes, &c.

In the seventh chapter, the principles developed in the preceding ones are applied to practical cases—of warming and ventilating dwelling houses, churches, schools, lecture-rooms, theatres, cotton-mills, and work-rooms.

And in the eighth chapter, a like application is made to hospitals, houses of equal temperature, &c.

The ninth chapter treats of the construction of stoves for plants, and other forcing-houses, green-houses, conservatories, hot-walls, &c.; and of the proportion of steam-pipe, of heat, and of ventilation for those buildings.

The tenth chapter is on the construction and proportions of grates and open fire-places, and the means of ventilating rooms warmed by open fires.

The eleventh chapter treats of drying by steam, the construction of drying-rooms, and the effect that may be produced, whether applied by the manufacturer on the large scale, or by private families. A family drying-closet is given as an example of the latter.

In the twelfth chapter, I have given a brief sketch of my own ideas respecting the nature of heat.

To facilitate the application of the principles contained in the work, I have given nine new Tables, with illustrative notes. In this edition the number of tables is increased, and the others much improved.

Each plate is described by an opposite page of letter-press, with references to the parts of the work they are intended to illustrate. A copious Index will also materially assist the reader in referring to a great variety of subjects which are incidentally noticed in the course of this treatise; and I hope he will be satisfied that I have spared no trouble to present him with a useful volume on a subject which has for a long time occupied my particular attention, and in which I have much professional practice.

16, *Grove Place, Lisson Grove,*
October, 1824.

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ERRATA.

Page 32, line 15, for *Kirvan* read *Kirwan*.

Page 103, line 11, for *greates* read *greatest*.

PRINCIPLES

OF

WARMING, VENTILATING,

ETC. ETC.

CHAPTER I.

A GENERAL VIEW OF THE ADVANTAGES AND DISADVANTAGES OF DIFFERENT MODES OF DISTRIBUTING HEAT.

"It is certain, that of all *powers* in *nature, heat* is the chief: both in the frame of *nature* and in the works of *art*." BACON.

ART. 1. ONE of the most valuable arts which Divine goodness has placed within our reach is that of producing and distributing heat. Destitute of this power, the condition of man in the world would not be much superior to that of the lower animals. It is a power which adds to our comfort any where, but acquires an additional value in the cold and variable climate of Britain. Hence, the art of applying heat has been studied with attention, and illustrated with talent; while it has been practised by men of no ordinary skill: yet still there appears to be a field sufficiently open for new and useful researches; for it seems to be possible to

combine an equal degree of safety, cleanliness, and comfort, with more healthiness and economy.

It will scarcely be needful to state, that, in dwelling-rooms, a genial warmth is all that is necessary, and all that is desirable; whatever the temperature is increased beyond this, is a direct cause of languor and debility. It unfortunately happens, that a higher degree of heat than is conducive to health, or even consistent with it, is found to be necessary in some manufactories; and its effect on the health of the workmen is too visible: perhaps it is materially increased by the alternate exposure of the system to the enervating heat of the warmest climates, and to the rigour of an English winter. I shall be happy, indeed, if any researches of mine shall be found useful in ameliorating the condition of these workmen; while so striking an evidence of the bad effect of hot rooms may be useful in correcting the prevalent disposition to indulge in them.

2. It must be obvious, that, in dwelling-rooms, the effect of the heat should be transient, that is, it should be incapable of producing a chemical change in any of the bodies heated: consequently, we have only two modes of applying heat, which will fulfil this condition; the source which supplies the heat should either be of a limited temperature, or so situate, that any substance on which it can produce a change may be immediately expelled.

It appears to have been fully proved that a dry heat, not exceeding 212 degrees, will not injure any

species of animal or vegetable matter, nor produce a sensible change in the quality of air. Therefore, in the first mode, we may employ a surface limited to 212 degrees, to warm the air of an apartment; but if a higher degree of heat be used, there will be a risk of producing what we term *burnt air*, which is neither healthful nor agreeable.

A well-constructed common fire-place affords an example of the second mode, where the source of heat expels all the noxious matter it generates. But, since the burning fuel is exposed, it is less safe than a source of heat of a limited temperature: every one must be familiar with the various accidents which happen in consequence,* and therefore, it is unnecessary to dwell on them here.

3. Before we proceed with our comparison, it is proper to remark, that a hot body affords heat by two different modes, that is, by contact, and by radiation.

Radiant heat spreads through air, and other gaseous bodies, with an immense velocity: and it passes through them without materially increasing their temperature, but it effectually warms the solid bodies exposed to its action. It is radiant heat we receive from the sun. It is radiant heat which we feel in approaching a common fire; it warms the solid matters of an apartment, and

* It has been estimated that in London there is an annual loss of five lives, and of property to the amount of £100,000, by fires; and that the average number of serious fires in a year is thirty-five. Napier's Supp. to Encyc. Brit. Vol. V. p. 293.

these slowly communicate the heat to the air; hence, in a room warmed by a common fire, a person may have a comfortable degree of warmth, and yet breathe in a comparatively cool atmosphere.*

Bodies at a low temperature, as, for example, when limited to 212 degrees, afford very little radiant heat;† the warmth they communicate is chiefly by contact, and the heat is diffused by means of the air, which, being gradually warmed by contact, is expanded and put in motion, and communicates the heat it receives to the solid bodies in the room. Therefore, our two distinct methods of communicating heat may be further distinguished; for, in the one case it is by *radiation*, in the other by *heated air*.

4. In a room warmed by heating the air, a person not actively employed does not feel a

* The advantage of a cool atmosphere to breathe in, is greater than most people imagine, for, according to the experiments of Crawford, Lavoisier, and others, it appears that the consumption of oxygen is less by 1-12th in an atmosphere of the temperature of 79° than in one of 54°. The diminution is greater than would result from the mere rarefaction of the air; and is attributed to a high temperature, counteracting the chemical changes which the blood undergoes in the extreme vessels. (Dr. Murray's Chemistry, IV. 511.) Elevated temperature, also, increases the quantity of insensible perspiration, and nearly in proportion to the quantity it is elevated, according to the experiments of Berger and De Laroche. (Encyc. Méthod. Physique, Art. Chaleur.)

† The quantity they afford depends much on the nature of the surface of the hot body. This subject has been carefully investigated by Professor Leslie, in his Experimental Inquiry into the Nature of Heat, Chap. II. To measure its intensity, he employed that delicate instrument called the differential thermometer.

comfortable degree of warmth when the thermometer is below 62°, though, in cold weather, that temperature feels oppressive to one who has been in the open air; indeed, the transition from breathing air at 20°, to air at 62°, which must often happen, is too great to be made without being felt. There must, therefore, be a sensible advantage in having to approach such a room through halls and passages, kept at a lower temperature, in order that the change may be gradual, and therefore less injurious.* If one's clothes have acquired any degree of dampness from a moist atmosphere, a chilling coldness is felt on entering a room filled with hot air. This feeling is caused by the powerful effect of warm air, in abstracting moisture. It absorbs moisture in the state of vapour, and this vapour requires a great quantity of heat for its formation, in the state which chemists term *latent heat*. Hence, the seeming paradox of a person getting cold by entering a room filled with warm air: the satyr in the fable was not more astonished at his guest blowing hot and cold with the same breath, than some people are at this assertion; yet it is perfectly true and easily understood, that a person in damp clothes, or in a state of perspiration, cannot enter a room filled with hot air without some danger; and the warmer the air of the room is, the greater this danger will be, because

* A gradation of light, Burke and Gilpin have shewn to be capable of heightening architectural effect; a gradation of heat, besides being pleasing to the senses at the moment, is likely to prevent disease and its attendant evils.

the evaporation will be quicker, and the sensation of cold more intense.*

From the same cause, when the external air is damp, a current of it, acting on any part of the body, is more likely to give cold than a much colder current of dry air, which is the chief reason of the prevalence of coughs and colds in damp weather, and particularly with those who are not much accustomed to be in the external air. When the weather is extrêmely cold, we rarely have a damp atmosphere, and, indeed, cannot have it, because cold air holds a less proportion of vapour in solution than warm air, (see note to Table VI. art. 221.) The specific heat of air is so small that it abstracts heat very slowly, but the latent heat of vapour is very great. It requires as much heat to form one cubic foot of vapour, as would raise the temperature of 130 cubic feet of air 10 degrees.

The continual absorption of moisture from the human body, which is a consequence of being in a bath of warm air, produces headache, the eyes feel wearied and painful, and the whole frame is disordered; if you saturate the air of the room with moisture, these sensations do not occur, or at least, in a less degree; but whether it be an advantage to

* A discursive view of the art of producing cold by evaporation, is given by Professor Leslie, (in the article Cold, Napier's Supp. to the Encyc. Brit.) shewing its application to freezing. Gay Lussac has made some interesting experiments on the degree of cold which evaporation produces, under circumstances nearly similar to those we have been considering. See Quarterly Journal of Science, Vol. XV. p. 294.

live in an atmosphere constantly saturated with moisture, or it is not, I will not pretend to determine.*

5. An apartment warmed chiefly by radiant heat is, in a great measure, free from these disadvantages, because the air is always cooler than the objects receiving heat from the fire. The rays of a fire produce no more vapour from moist bodies than they supply with heat: and, therefore, they produce no cold when unaided by the affinity of warm and dry air. Moisten the bulb of a thermometer, and expose it to the action of warm dry air, it will sink down several degrees; but when moistened and exposed to the rays of a fire it rises.

It will be said, that in colder and damper climates than ours, rooms are successfully warmed by heated air;† but let it be remembered that these

* In a stove which has been lately introduced, a vessel of water is placed on the stove for the purpose of saturating the air with vapour, and Mr. Murray has remarked, "that among the Appenines, the Italians place a shallow earthen vessel, supplied with water, on the head of the stove." On inquiring the reason, he was repeatedly assured "that without it they would be subject to head-ache and other ills—while, with this simple precaution, they experience no inconvenience whatever." Philosophical Magazine, Vol. LVIII. p. 387. The same precaution is taken in using the Swedish stoves. (Repertory of Arts, &c. Vol. VII. p. 70. old series)

† I say *successfully*, but to warm a close room, presents no difficulty; its effect on health is the important question; this may be somewhat illustrated by a note which is given, by the benevolent Howard, in these words: "In conversation with the physician of the military hospital at Moscow, on my observing that the

climates are less variable than that of Britain; that, being regular, they are regularly provided for, and with a degree of care which is wholly unknown in this country. Therefore, the success of their methods is a very insufficient reason for introducing them where the state of the atmosphere, and the ideas of comfort and convenience, are altogether different. An Englishman may imitate the cautious habits of the people of colder climates, but he cannot change the variable nature of his own. The use of heated air has been adopted through necessity; the natives of still colder regions are compelled to adopt still more economical means of obtaining warmth; but fortunately for us, with other and more varied sources of gratification, we have also the advantage of abundance of fuel.

A person warmed by radiant heat is, however, always unequally warmed; and, if the introduction of cold air be injudiciously managed, he may literally burn on one side and starve at the other; but, in ordinary cases, the inequality of heat is not greater than that which allows some latitude of choice in selecting an agreeable temperature. It is certainly an overstrained idea of comfort to suppose an absolute equality of heat desirable.* In nature

windows of the wards were shut, he answered, 'Almost all our disorders are in the winter, for the *Russians* inclose themselves in hot rooms, and dislike the fresh air, even before the cold months commence.'" See Account of the Principal Lazarettos of Europe, p. 231.

* The opinion that equality of heat is desirable, is supported by Mr. Sylvester: (Quarterly Journal of Science, Vol. XI. p. 231, or Philosophy of Domestic Economy, p. 53.) when he says "we ought

it is not so; the sun warms us by radiant heat, and, consequently, unequally; we never feel heat oppressive nor injurious till the air becomes hot; and if there be an inconvenience in that inequality of heat, which, we must be sensible, has place every time the sun shines, it is an inconvenience I have never felt; the cool freshness of the air, and the warmth of the sun's rays, are sensations most pleasurable when united. Plants, in the natural state, are also exposed to inequality of temperature; and those who have cultivated them with most success, have found that uniform heat is not desirable, when it is applied artificially. An imitation of nature in treating plants has been attended with sufficient advantage to shew that it is the proper course to be followed. (See Chap. IX. where the subject is more fully explained.)

But warming by radiant heat can be applied only on a small scale, unless it be in conjunction with other methods; for an intense source of heat would be insupportable; and since the heat diminishes as the square of the distance from the hot body, its extent is very limited. We cannot employ many fires without much trouble and inconvenience, besides a risk of smoke. And, since the heat of the

to have the benefit of its temperature and its oxygen at the same time," he forgets that rarefied air must render respiration more laboured to acquire the same portion of oxygen in a given time, and without any other advantage. A given bulk of air at an inferior temperature, says a medical writer, contains more of the oxygenous principle, than the same bulk at a superior degree of heat; hence, the greater refreshment which is experienced from the inhalation of a cold and dense, over that of a warm and rarefied atmosphere.

source must not only be intense, to extend to a distance, but also freely exposed, it is a dangerous mode of obtaining warmth in many cases. It is also objectionable on account of the dust, smoke, and ashes which are inseparable from this method of distributing heat.

Radiant heat, then, being improper for warming a large horizontal space, we must next proceed to inquire respecting other methods.

6. Where we cannot employ radiant heat, there seems to be no other plan of heating which could be conducted with advantage, except some one which diffuses heat by means of the air; but the modes of heating air for this purpose are various. The most distinct are, those where the air is heated in the place to be warmed; and those where the air is heated in a separate place, situate below the level of the place to be warmed. The combination of these principles is, however, better than either of them separately, because, where the heated air has been elevated to a temperature far exceeding that which is required in a room, it seems to lose its freshness, and becomes vapid and enervating: whether it be owing to its state of electricity being altered by contact with metal at an elevated temperature, or to some other cause, it is difficult to ascertain; but where there is no necessity for exposing it to a high temperature, it seems well to avoid it. Now, we cannot effectually warm one room by air heated in another, without raising the temperature to such an excess as will compensate the loss of heat in the

room to be warmed. This excess will differ according to the nature of the room, and the quantity of air introduced in a given time. I have noticed the temperature of air admitted in a few instances, and found it vary from 100° to 130°.

We have now to consider the methods of distributing heat, so that the heating surface may be of a limited temperature.

7. Steam is a vehicle for conveying heat, which, when employed at a low pressure, will never give to the surface containing it a greater heat than that of boiling water, or 212°; and when that surface is of a proper material, it produces no sensible effect on the air, it can be conducted to any part of a building with the utmost facility, and is unquestionably safe.*

Hot water may also be employed in some circum-

* Col. William Cook first suggested the idea of employing steam as a means of distributing heat, in 1745. (Philosophical Transactions, Vol. XLIII. p. 370, or Abridgment, Vol. IX. p. 125.) It has since been applied in various ways, most of which have been repeatedly secured by patents. The first of these was granted to John Hoyle of Halifax, in 1791, for a method of communicating heat to green-houses, churches, &c. His plan consisted in conveying steam in pipes or tubes, into, round, or through the place to be warmed; the pipes being first raised to their highest elevation, and then descending with a gentle declivity to a cistern for the condensed steam; the supply of water to the boiler to be regulated by a ball-cock. (Repertory of Arts, Vol. I. p. 300-303, old series.) This scarcely differs in any thing from Col. Cook's plan, which had been known forty-six years sooner. In 1793, a patent was granted to Joseph Green, whose mode of application was different, and has had the honour of being adopted with slight

stances for conveying heat, but not with more advantage, even in those particular cases, than steam.* In all hot-water apparatus, it is steam which distributes the heat; for we cannot employ such a force of heat as would cause water to circulate through pipes by a change of density, without converting it into steam; as may easily be proved by the doctrine of hydraulics.

But, by combining the two modes, we have a more economical and better system of distributing heat than by employing steam alone. Mr. Knight proposed the combination of these modes;† it appears, however, to have been practically used before.

8. Air may be made the means of distributing

alteration of form, by a number of later projectors. His method consisted in passing fresh air through a worm, or pipe, immersed in *hot water* or *steam*, by which means the purity of the air was to be preserved. When the heat was to be conveyed to a distance, he says, "I inclose the pipes through which the warm air is conveyed in large pipes, to which the steam rises from the boiler." (Repertory of Arts, Vol. I. pp. 21, 24, old series.) Col. Cook's idea was neglected, no doubt, because it promised too much. Whoever attempted to warm a large suite of apartments by the spare heat of a kitchen fire would fail; because, so small a quantity of heat is quite inadequate to produce such an effect: but when revived with less pretension, steam was found to be a convenient and economical means of distributing heat.

* It was proposed by Mr. R. Weston to heat pine stoves and beds with hot water, (Repertory of Arts, Vol. XIII. pp. 238 and 314, old series,) and Bosc mentions a trial to heat a hot-house by hot water at the Jardin du Muséum. Encyc. Méthod. Agriculture, article Serre.

† Transactions of the London Horticultural Society, Vol. II. p. 324.

heat, when the surface from which the air derives its heat is every where at such a distance from the burning fuel that it cannot acquire more than the limited temperature. This is the principle of the cockle which Mr. Strutt adopted in 1792, to warm his cotton-works; and afterwards applied to warm the Derbyshire General Infirmary.* In theory, Mr. Strutt's cockle is a simple and elegant application of principles, to attain the whole effect of the fuel, and in less skilful hands must have failed entirely as far as regards economy; but in practice, it requires a building to be provided for it; otherwise, it is a cumbrous mass, which it is difficult to find a place for; and still more so to give a tolerable appearance to the parts, which ought to be ornamental as well as useful. The fire-place it is necessary to sink considerably below the space to be warmed; and it must be nearly under it; the air must be all heated in a separate space from that which is to be warmed, which causes a loss of heat without an adequate degree of ventilation, and we cannot ventilate from the proper place.—(See Chap. IV. art. 62.)

The principle of not suffering air to be in contact with any substance heated above 212 degrees, excludes a multitude of contrivances called stoves, which it would be a waste of time to examine. The

* Philosophy of Domestic Economy, p. 22. The invention of the cockle itself is old, but was never before applied with so much science. John Pepper had a patent in 1796 for applying it to drying malt, &c. calling the cockle a reflector. Repertory of Arts, Vol. V. p. 289, old series.

fire-places are generally formed of materials which conduct heat most rapidly, and the fuel is deprived of its heat so quickly, that combustion is never perfect; the natural consequence is a great waste of coals.

9. But there is yet another mode of distributing heat, with the advantage of preventing the air being in contact with a surface heated above 212 degrees. It consists in confining the burning fuel within a proper thickness of matter, generally of a slow conducting power. The material usually employed is brick; and the flues of hot-houses have always been formed in this manner; whether from principle or convenience, it is difficult to ascertain. The extent to which heat can be carried by this method is very limited; but if the materials were unexceptionable, it is much the best and most simple method of heating air on a small scale. Common bricks are not proper, because they contain sulphureous matter which sublimes at a low temperature; they are also liable to open at the joints from the expansion of the heated air in the flues,* and which very frequently breaks the solid bricks. Through the fissures thus caused, the noxious gaseous matter and vapour from the fuel makes its way, and mixes with the air to be warmed. In a place heated by these stoves, the contamination

* In a stove of this kind for warming a meeting-house for the Society of Friends at York, double walls to a certain extent were employed, built in contact, and so that none of the joints were opposite. See Alexander's Observations on Meeting-houses, p. 29, York, 1820.

of the air is readily detected by the peculiar odour given out.

It would not be difficult to obviate this fault. For if a case of iron were contrived in such a manner that it would not break by irregular expansion, and be perfectly air-tight, with a lining of brick of such a thickness and extent as would limit the temperature of the surface of the iron to 212 degrees, it would form an excellent stove. A stove of this kind, when insulated so as to experience no loss of heat, and with sufficient length of flue to obtain the whole effect of the fuel, will be very effective.

The various forms of stoves, called Swedish, are only variations of this principle; where a case of glazed tiles is used instead of a case of metal, and there has not always been strict attention paid to limiting the temperature of the surface for heating the air. When Guyton Morveau investigated the Swedish stoves with the view of introducing them in France,* he so far deviated from his models, as to heat part of the air by iron plates that were in contact with the burning fuel; and, consequently, made them liable to the worst objection against the German stove, that is, of producing burnt air.

10. We have now considered the means that have been applied, or may be applied, to diffuse warmth; and on comparing them it will be found that steam combines all the advantages of the best, and has not the defects of the others, when employed on a con-

* Repertory of Arts, Vol. XVI. p. 255, old series.

siderable scale. It has been found equally good in practice, being, in the words of Mr. Brande,* safe, salubrious, and economical; and Dr. Ure remarks, "The people who work in steam drying-rooms are healthy, those who were formerly employed in the stove-heated apartments, became soon sickly and emaciated."† Steam has also been found to afford a heat extremely favourable to the growth of plants; it gives the power of filling the house with steam at pleasure, which, when done at a proper time, covers the plants with dew, resembling the dew of nature, and equally beneficial. A dew cannot be cast on the plants by the usual process of steaming from flues, without rendering the whole house dripping wet, and an excess of heat is necessary for some time afterwards, to prevent the cold that would be a consequence of the evaporation of so much moisture. We are indebted to the late Dr. Wells for a knowledge of the principles which regulate the formation of dew,‡ and a simple application of them enables us to imitate the process of nature in casting dew upon plants. In an article on forcing-houses and stoves, written by Mr. Neill, he says, "Of recent improvements, however, in this branch of gardening, the most important is the use of *steam* for communicating the artificial heat, in place of depending, as formerly, on the passage of smoke and heated air through flues." § The

* Napier's Supp. to Encyc. Brit. art. Chemistry, p. 9.

† Dictionary of Chemistry, art. Caloric.

‡ Essay on Dew.

§ Napier's Supp. to Encyc. Brit. article Horticulture, p. 660.

opinions of other eminent horticulturists are equally favourable.* Steam is employed on the largest scale by Messrs. Loddiges, at Hackney, and I have no where seen stove plants in greater perfection and vigour. They have now (1824) used steam above five years, and with success. In their large stove, which is about 100 feet in length, 60 feet in width, and 40 feet in height, the magnificent plants of the tropical climates are aspiring to their native grandeur. When their establishment of houses was somewhat less extensive than it now is, they published a description of their method of heating it by steam, wherein they remark, "that steam does not contaminate the air as flues invariably do, thereby rendering it unfit for vegetation: on the contrary, the heat obtained from steam is regular and congenial to all plants; it is also far more salubrious and pleasant to the human lungs than any other artificial heat whatever."† The description is concluded with a few remarks on the advantages of cultivating tropical plants, filled with expressions of pious gratitude and admiration, which the grand and beautiful specimens they have collected of the wondrous works of our Creator are so well calculated to produce.

11. It is very commonly asserted, that steam-

* Transactions of the London Horticultural Society, Vol. II. p. 320. Wakefield's Account of a Method of forwarding Vegetation by means of Steam. Transactions of Society of Arts, Vol. XVIII. p. 393. "Journal of a Horticultural Tour through Holland," &c. p. 4 and 507. 8vo. 1821.

† On Warming Hot Houses by Steam, p. 6. 1818.

heat is more economical than that of smoke-flues; I do not know how the comparison has been made by others, but he must be a novice in the science of heat, that cannot produce nearly the same effect by the one as by the other, all other circumstances being the same.* I know that, in either method, it is easy to mismanage things in such a manner, that not more than half the heat will be effective in warming the intended space; and that, by selecting cases for comparison, you may make either appear to be the best method, as far as regards economy of heat. It is the contemptible resource of a quack to have only one method for all cases: the man of real knowledge will in each case apply that method which is best adapted to produce the desired effect Since the invention of the steam-engine, the construction of boiler fire places has been a subject of so much importance, that it has been more generally and carefully studied than the construction of furnaces and smoke-flues; which will account for the results of some comparative experiments making steam appear more economical.

One important advantage is obtained by a steam apparatus, which distinguishes it from every other method of distributing heat, which is, that it can be extended to a very great distance from the boiler, in every direction: we can cause it to ascend, descend, or move horizontally, with equal facility; the

* Some experiments were made by Mr. Atkinson, the results of which he communicated to me; and, comparing these with my calculations for steam, I find the difference to be very small; but his flues are very superior ones, and also his fire-places.

loss of heat is inconsiderable in conveying it to a distant point: hence, one single fire is sufficient for an immense establishment, and this one may be placed where the smoke of a chimney is least offensive, and its appearance least objectionable—this is of some importance in ornamental gardening; on the plan with smoke-flues, the great number of chimneys is a serious evil. The distance from the boiler to the end of the most distant house, at Messrs. Loddiges, is about 800 feet, and it does not appear to be carried to the greatest extent; hence, the largest manufactories, or workshops, and the most considerable arrangement of forcing-houses and stoves, may be heated from one point. (See Plate IX.)

But, wherever steam is employed, it should be under the direction of a person competent and willing to attend to it. For, though in such hands it is perfectly safe and easily managed, it is by far too complicated to be trusted in the hands of careless and ignorant people. The apparatus must be kept in order, and though only a small degree of attention be necessary for that purpose, it does not admit of neglect. The supply of fuel, also, requires more frequent renewal than in common furnaces.

12. Hence, in an establishment of forcing-houses, where the attendance on many fires can be reduced to attending on one, and where a proper attention would be given, I would prefer steam; but, in other cases, flues will be found to answer better. The manner of constructing and applying these flues, makes a considerable difference in their

power of affording heat. The best I have seen are those done under the direction of Mr. Atkinson; which are very effective, and remarkable for neatness and excellent workmanship. It requires considerable management to render flues capable of giving an uniform temperature to a house, and it is a serious defect in a forcing-house to have the progress of vegetation different at every different part of its length. The materials ought to be very carefully selected, and every precaution against the escape of vapour and gas from the fuel, should be put in practice. As soon as the smoke has arrived at such a distance from the fire, that its temperature is less than 212°, cast-iron pipes might be used with advantage to carry off the smoke, because they would afford more heat, and at the part of the flue most distant from the fire, where heat is most required.* A high chimney will be found to make a considerable difference in the quantity of effect that can be gained from smoke flues; because a rather forcible draught is required to make the smoke circulate through much extent of horizontal flue. If the chimney be a low one, the only method of procuring the required degree of draught is to let the smoke ascend at a higher temperature. (The

* By the usual method of employing a slow conductor for the whole length of the flue, a part of the heat is lost, and the smoke escapes at an elevated temperature. This effect of slow conductors is well illustrated by Experiment XIII. of Professor Leslie's Inquiry into the Nature of Heat, p. 38, and has been also alluded to by Mr. Knight, (Transactions of the Horticultural Society of London, Vol. II. p. 325.)

principles of the ascent of smoke in chimneys are considered in the fifth chapter, art. 93.)

When the circumstances are attended to which have now been noticed, it will be obvious that smoke-flues, might in several cases, be employed with advantage.

The selection and the effect of different species of fuel, is another subject which requires a little investigation, and shall form the subject of the next chapter.

CHAPTER II.

OF FUEL, AND ITS POWER OF PRODUCING HEAT, STEAM, &c.

"To estimate the quantity of heat evolved during the burning of different combustibles, is not only important in a philosophical point of view, but of considerable consequence also as an object of economy." THOMSON.

13. THE first advances in the art of applying heat will be perhaps best made by studying the nature of the substances usually employed for obtaining it; and in endeavouring to ascertain the quantity of heat each kind of fuel will produce. These researches will also inform us, when it is that we have obtained the greatest possible effect, and prevent us from running into those wild speculations which some men indulge in; as they did in trying to obtain a perpetual motion, in an age when the immutable laws of mechanics were less understood; or in attempting to convert the baser metals into gold, in the infancy of chemical science.

We may consider the nature and effect of fuel when it is employed in its natural state; and also when it has been prepared artificially. To the first class belong coal, wood, peat, turf, &c.; among the latter kind coke, cinders, charcoal, clay-balls, &c. may be comprehended.

14. When an intense heat is either to be produced in a short time, or to be sustained with great energy, it is always found necessary to employ fuel in its natural state. But a regular heat is most easily sustained with prepared fuel, and with much less attention; it is also a more economical means of obtaining a slow and regular heat. Hence the object to be obtained will, in general, determine the nature of the fuel which ought to be employed for accomplishing it. In an apparatus for generating steam, it is desirable to raise the water in the boiler to the boiling point as speedily as possible; but this being done, it will be most economical to produce a regular heat by means of a slow burning fuel, in order to keep up the supply of steam. For this purpose coke may be employed with great advantage, or a mixture of coal with small cinders, (such as the refuse of the London fires, commonly called *breeze.*) But these kinds of fuel cannot be obtained in many places.

15. Whatever kind of fuel it may be considered best to employ, it is extremely desirable that it should be as dry as possible, otherwise a great part of the heat it contains will be lost in converting the water in the fuel into vapour; which of course escapes up the chimney without producing any useful effect. It was Count Rumford, I think, who first noticed the loss of effect by employing moist fuel;* and it is the more necessary to point out this

* Essays, Vol. II. p. 88.

circumstance to the notice of my readers, because fuel is often unnecessarily exposed to the weather, or put in wet places; and the injurious effect of introducing damp into a close fire-place is never considered.

16. In order to compare the effects of different kinds of fuel, some convenient measure of effect should be adopted; not only for the purpose of lessening the trouble of calculation, but also to render it more clear and intelligible. I shall, therefore, without regarding the measures of effect employed by others, adopt one of my own, which I have found useful in this and other inquiries of a similar nature.

I take, as the measure of the effect of a fuel, the quantity, in pounds avoirdupois, which will raise the temperature of a cubic foot of water one degree of Fahrenheit's thermometer.

17. And since the boiling-point, or 212°, is 180 degrees above the freezing-point, the quantity of fuel that will heat a cubic foot of water one degree, being multiplied by 180, gives the quantity that would make a cubic foot of ice-cold water boil.

And, in like manner, by taking the difference between 212, and the actual temperature of the water when supplied to the boiler, and multiplying the quantity of fuel that will heat a cubic foot of water one degree, by this difference gives the quantity of fuel that will make the water boil. When the water is at the mean temperature, or

52 degrees, then the difference is 160°, and it only requires seven-eighths of the quantity that would boil ice-cold water.

18. Also the fuel that will convert a cubic foot of boiling water into steam, will be found by multiplying the latent heat of steam by the quantity of fuel that will heat a cubic foot of water one degree. Dr. Ure, from some accurate experiments, found the latent heat of steam to be 967°;* therefore, multiplying the quantity of fuel that will heat a cubic foot of water one degree, by 967, will give the quantity that is required to convert boiling-hot water into steam.

But when the whole quantity of fuel is required which would convert water into steam from the mean temperature, or 52°, then add 160 to 967, which makes 1127°, and multiply the quantity of fuel that would heat a cubic foot of water one degree by 1127, and the product will be the quantity of fuel in lbs. that would convert a cubic foot of water into steam from the mean temperature. Dividing 1127 by 160, the quotient is 7 nearly; consequently, 7 times the quantity of fuel that will boil a given quantity of water from the mean temperature, will convert the same quantity of water into steam.

19. In most of the experiments on fuel, the

* Philosophical Magazine, Vol. LIII. p. 194. The experiments of Mr. Watt led him to give 960° as the latent heat. (Robison's Mechan. Phil. II. p. 8. Mr. Watt's note.)

number of lbs. of ice a given quantity of fuel is capable of melting, has been ascertained; and when such experiments are made with great precision, the whole quantity of heat a given portion of fuel will afford, may be more nearly ascertained by this than by other methods. Now, $62\frac{1}{2}$ lbs. of ice is equal to a cubic foot of water; and, according to Dr. Black's experiments, the latent heat of water is 140°,* consequently, 140 times the fuel that will heat a cubic foot of water one degree will melt $62\frac{1}{2}$ lbs. of ice.

20. The heat necessary to raise the temperature of a cubic foot of water being known, that which will raise the temperature of a cubic foot of any other body one degree, may be readily ascertained, if the specific heat of the body has been found. One or two examples will be sufficient to illustrate the method of proceeding.

If you would ascertain the quantity of fuel that would heat a cubic foot of air one degree, then the specific heat of water being 1, that of an equal bulk of air is 0·00035, or $\frac{1}{2850}$; (See art. 217, Table II.) and if the quantity of fuel that will heat a cubic foot of water one degree, be multiplied by 0·00035, the product will be the quantity of fuel that will heat a cubic foot of air one degree; and 20 times that quantity will heat it 20 degrees; 30 times will heat it 30 degrees, and so of any other temperature.

* Dr. Thomson's System of Chemistry, Vol. I. p. 93.

And the same quantity of fuel will be capable of heating the same quantity of any other gas the same number of degrees as common air, because the specific heats of equal bulks of all gases are nearly equal under the same pressures. (See art. 217.)

21. If the quantity of fuel that would raise the temperature of a cubic foot of iron one degree be required, then the specific heat of iron is 0·95, (art. 218.) that of an equal bulk of water being unity; and therefore multiply the quantity of fuel which would heat a cubic foot of water one degree, by 0·95, and the product will be the quantity necessary to heat a cubic foot of iron.

By these simple calculations, we can compare the results of numerous experiments, and reduce them to a common standard; we can investigate the advantage of various modes of applying heat, and the best methods of applying fuel.

Pit Coals.

22. There is considerable difference between the pit coals; and it has perhaps been too little attended to by those who are the chief consumers of this expensive article. The subject has not even been studied with much attention, except as far as relates to producing gas; and the facts that have been established by these researches, are not very useful in other applications of fuel. A most valuable Paper, on the "Composition of the different species of Pit Coal," has, however, lately

appeared, written by Dr. Thomson,* who has arranged the kinds he submitted to experiment under the following divisions:—

1. Caking coal. 3. Cherry coal, or Soft coal.
2. Splint coal. 4. Cannel coal.

These four divisions, it is probable, will include the most important varieties used in Great Britain; † and, indeed, for our purpose, the latter one may be omitted. I shall follow Dr. Thomson's arrangement, and, with the assistance of his researches, and those of Kirwan and others, shall endeavour to form a brief, but useful, outline of the subject.

23. *Caking Coal*—(also called binding coal, crozzling coal, &c.)—is obtained in great abundance from the extensive coal fields of Northumberland and Durham, and is sold in the London market as Newcastle coal.‡ The different beds or seams afford coals which differ considerably in quality. Caking coal is also obtained at Whitehaven in Cumberland; Wigan, in Lancashire; Swansea, in Wales;

* Dr. Thomson's Annals of Philosophy, Vol. XIV. p. 81.

† A general view of the geological relations of the coal fields of Great Britain is given in Messrs. Conybeare and Phillips' Outlines of the Geology of England and Wales, Book III. p. 233. See also Desmarest's Géographie-Physique, Tome III. p. 368. Of particular coal fields several have been described. The Derbyshire coal field was minutely and carefully investigated by Mr. Farey. (Derbyshire Reports, Vol. I. p. 161.)

‡ Dr. Thomson's Annals of Philosophy, Vol. IV. pp. 337 and 410; Vol. XIV. p. 81.—Kirwan on the Composition, &c. of Coals. Repertory of Arts, Vol. XIII. p. 249, old series.—Outlines of Geology of England and Wales, p. 380.

Leitrim, in Ireland; and from a few of the coal seams in Derbyshire; also from some of those in the neighbourhood of Glasgow, and other places in Scotland.*

Caking coal is black, soft, and easily broken; the fragments have more or less of a cubical shape: it is brittle, and soils the fingers. Dr. Thomson found its specific gravity 1·269, and the varieties tried by Kirwan gave nearly the same result. When heated, it breaks asunder into small pieces; and the heat being raised to a certain degree, the pieces cohere, and form a solid mass. Hence it is called *Caking coal.* It lights easily, and burns with a lively yellow flame: it requires to be frequently stirred or broken up, particularly when it cakes very hard; but different varieties differ considerably in this property. Of the Newcastle coals, the best Wall's-end make a brilliant and pleasing fire, burn away quickly, and do not cake hard; but the Tanfield-moor burn slowly, cake very hard, and afford a strong and long-continued heat; the other varieties are of an intermediate character. The Whitehaven coal burns at first with a clear flame, and for a long time, but at last cakes. The Wigan coal burns quicker, and cakes less. The Swansea coal burns slowly, and cakes. The Leitrim coal cakes only slightly.

Caking coal gives out a great quantity of heat, and, with attention, burns a long time; consequently,

* The custom house return of coal brought to the London market in 1820, is 1,321,905 chaldrons, besides the quantity brought by the Grand Junction Canal from Staffordshire. (Supp. to Encyc. Brit. Vol. V. p. 288.

where it can be procured at a reasonable price, it is commonly preferred.

According to Dr. Thomson's experiments, 1000 lbs. of caking coal afford 774 lbs. of coke, when prepared in close vessels: the quantity would be less, if prepared in the open air; and this coal contains 1¼ per cent. of earthy matter.

From the trials of Mr. Watt, it appears that a bushel of Newcastle coals will convert from 8 to 12 cubic feet of water into steam, from the mean temperature of the atmosphere;* and a bushel of Swansea coal will produce an equal effect.† The mean weight of a bushel of coals being 84 lbs. and, taking 10 cubic feet as the mean effect of a bushel, it will be found equivalent to heating one cubic foot of water one degree, with 0·0075 lbs. of coal.

Consequently, 1·2 lbs. of coal would boil a cubic foot of water from the mean temperature, (by art. 17.) and 8·4 lbs. of coal will convert one cubic foot of water into steam, from the mean temperature, (by art. 18.) Also, 1·05 lbs. of coal will melt 62·5 lbs. of ice, (by art. 19.) And it will require 0·00000262 lbs. of coal to heat one cubic foot of air one degree, (by art. 20.)

A comparison of other experiments will shew that these data may be used with confidence. Dr. Black states to the effect, that 7·9 lbs. of the best Newcastle coal will convert one cubic foot of water into steam, capable of supporting the mean pressure of

* Notes to Robison's Mechan. Philos. Vol. II. p. 147.

† Idem, Vol. II. p. 145.

the atmosphere.* In some experiments tried by Messrs. Parkes, it appears that, by their improved method of constructing boilers, an effect was obtained, equivalent to converting one cubic foot of water into steam from the mean temperature, with 7·45 lbs. of coal, in the case where the greatest effect was produced; but at a mean, 8·15 lbs. of coal were necessary to produce the same effect;† which is only one quarter of a pound less than the mean of Mr. Watt's statements. From a mean of several experiments, Smeaton makes it require 11·4 lbs. of coal to produce the same effect;‡ but the kind of coal is not described. From a mean of several experiments, Hassenfratz found that 0·65 lbs. of coal would melt 62·5 lbs. of ice, and his lowest result is 0·81 lbs. to melt that quantity.§ I found that after the brickwork, &c. of a boiler was warmed, a little less than 1 lb of Wall's-end coals would make a cubic foot of water boil, from the mean temperature of 52 degrees. To produce the same effect with inferior coals, a stronger draught, and more time and attention, was necessary.||

* Lectures on Chemistry.

† Quarterly Journal of Science, Vol. XIII. p. 61.

‡ Rees's Cyclopædia, art. Steam Engine.

§ Dictionnaire de Physique, Tome II. 475.

|| The reduction of experiments to a standard measure of effect is extremely useful; in many cases it will spare the trouble of comparative trials, and in others prevent illusory ones. For example, it was lately stated in a pamphlet, that 34 gallons (or 5·55 cubic feet) of water, required 126 lbs. of coal to evaporate it. Now, it will be found that the same quantity ought to be evaporated by 46·6 lbs.; consequently there is a material difference in the apparent advantage of the process which is proposed in the pamphlet.

24. *Splint Coal, or hard coal,* (slaty Cannel coal of Kirwan.)—The best varieties of this species of coal are esteemed equally as valuable, for many purposes, as the Newcastle caking coal. It is obtained near Glasgow, and in Ayrshire, in Scotland, and in several of the English coal fields.* Culm, coarse coal, and stone coal appear to be inferior varieties of this species.

The colour of splint coal is black, with a shade of brown. It is less easily broken than caking coal, and has a splintery cross fracture; whence most probably its name of splint coal. The fragments are commonly inclined to wedge-shaped. The specific gravity variable according to Dr. Thomson, 1·290: and Kirvan, 1·426.

A greater heat is necessary to make it kindle than is required for caking coal, and consequently it is not so well adapted for a small fire; but a large body of splint coal makes a strong and lasting fire. It does not produce so much flame, nor so much smoke, as caking coal, and does not agglutinate or bind together.

Dr. Thomson acertained that 1,000 lbs. of splint coal will afford 647 lbs. of coke, when it is prepared in a close vessel, and it contains 9½ per cent. of earthy matter.

The best splint coal of Scotland was considered by Smeaton to be equal to Newcastle coal, for steam engines.† This might be expected from the

* Dr. Thomson's Annals of Philosophy, XIV. 83.—Kirwan, Repert. Arts, XIII. 246, old series.—Outlines of Geology, p. 380.

† Reports, Vol. II. p. 361.

constituents of these coals, as determined by Dr. Thomson's experiments; and the same measures of effect may be employed without material error.

Culm is variable in quality; compared with Newcastle coal, of the best quality, the weights necessary to produce the same effect appear to be as 2·6 is to 1.* Hence, it will require 0·0196 lbs. of culm to heat one cubic foot of water one degree; and 22 lbs. to convert a cubic foot of water into steam from the mean temperature.

25. *Cherry Coal, or Soft Coal.*—Dr. Thomson says, it constitutes the greater part of the upper seams of coal in the Glasgow coal fields; and that it is abundant in Fifeshire; he considers the Staffordshire coal to be of the same species; and the Edinburgh as intermediate between it and splint coal.

Cherry coal is velvet black, with a slight gray shade; it has about the same degree of hardness as caking coal, and is as easily broken; so that there is much waste in working it: and as it does not cake, the small coal is not saleable, except for furnaces. In the coal fields on the north and north-west of Birmingham, the loss in mining amounts to about two-thirds of the seam of coal.† The waste in domestic processes, which Count Rumford lamented so much, dwindles to nothing, in comparison with this wholesale destruction of an invaluable material. Are you a manufacturer? Look around, and see what generates the power which enables you to

* Brunton's Compendium of Mechanics, p. 100.

† Dr. Thomson's Annals of Philosophy, vol. viii. p. 169.

compete with other nations. Are you a philanthropist? Consider that a substance is destroyed which would add comfort to millions of our fellow-creatures; consider the risk at which it is procured, the number of lives that are lost by explosions, and the misery these catastrophes create. Surely, some means of rendering that portion useful which is now wasted might be devised.

Cherry coal is more brittle than caking coal: the fragments are rectangular, and, according to Dr. Thomson, its specific gravity is 1·265.

It readily catches fire, and burns with a clear yellow flame, giving out much heat; and the flame continues till nearly the whole of the coal be consumed. It burns away more rapidly than either caking or splint coal, and leaves a white ash; and for most purposes, it is less economical. It is easily distinguished from caking coal, by its not melting or becoming soft when heated; it makes a more agreeable fire, and does not require to be stirred. It requires care and management in an open grate, even to burn the small fragments which are made in breaking up the pieces to a fit size for the fire: hence, the small coals are often mixed with clay, and made into balls. When these balls are dry, they make an excellent addition to the fuel for an open fire, producing a very durable heat.

According to Dr. Thomson's experiments, 1000lbs. of Cherry coal will produce about 522 lbs. of coke, when prepared in a close vessel; and it contains 10 per cent. of earthy matter.

From a comparison of some indirect experiments,

its effect in producing heat is from one-fourth to one-third less than caking coal; which agrees with Mr. Watt's statement, that one cwt. of good Wednesbury coal will produce the same effect as one bushel of Newcastle coal.*

26. It is only lately that the constituents of Pit Coal have been determined in such a manner as to elucidate the phenomena of combustion; and to enable us to judge of their effects in producing heat. The experiments shew the elements which constitute pit coal, without noticing those which are esteemed accidental mixtures.

Constituents of one-hundred parts of Pit Coal by Weight.†

	Carbon.	Hydrogen.	Azote.	Oxygen.	Experiments by
Caking Coal	75.28	4.18	15.96	4.58	Dr. Thomson
Splint Coal	75.00	6.25	6.25	12.50	Do.
Do.	70.90	4.30	none	24.80	Dr. Ure
Cherry Coal	74.45	12.40	10.22	2.93	Dr. Thomson
Cannel Coal	64.72	21.56	13.72	none	Do.
Do.	72.22	3.93	2.80	21.05	Dr. Ure

Dr. Thomson's experiments agree very well with known facts respecting the different species of coal; but it seems that Dr. Ure has not been furnished with a specimen of real cannel coal, otherwise it would have contained a greater proportion of hydro-

* Notes to Robison's Mechan. Philos. Vol. II. pp. 145, 147.

† Dr. Thomson's Annals of Philosophy, for August 1819, Vol. XIV. p. 95, and Dr. Ure's from the Quarterly Journal of Science, Vol. XIV. p. 390.

gen; or, perhaps, the quantities of hydrogen and oxygen have been entered by Dr. Ure in the wrong columns. Dr. Thomson remarks, on his own trials, "These experiments, imperfect as they are, will serve materially to guide manufacturers in the choice of their coal, according to the peculiar objects they have in view. We see from them, that the goodness of a coal does not depend so much upon the absolute quantity of carbon which it contains, as upon the proportion which exists in it between the carbon and the hydrogen. When the object is to convert the coal into coke, or when we wish to make it subservient to the production of long continued and intense heat, we must make choice of the species which contains the greatest proportion of carbon and the smallest of hydrogen. On the other hand, when the object is to procure coal gas, we must choose the species which contains the greatest proportion of hydrogen compared to that of carbon."*

It also may be remarked, that azote being incombustible, and requiring much heat to convert it into gas, the effect of a fuel will be greater when less azote enters into its composition; if we knew a mode of causing it to remain in the solid state, it would then be neutral, in respect to the generation of heat; perhaps, the true cause of azote giving out no heat in entering into new combinations, is, that it produces gaseous compounds, which require as much heat as their constituents.

* Annals of Philosophy, Vol. XIV. p. 95.

When a fuel contains oxygen, that oxygen will carry off as much heat as is necessary to give a gaseous form to the combination it enters into, unless it happens to form a condensible gas, and in the latter case it will be neutral. Hence it appears, that it is not desirable a fuel should contain either oxygen or azote.

A fuel which contains hydrogen, must lose a great portion of its effect whenever the hydrogen escapes in the state of gas from the burning fuel; for the latent heat of hydrogen gas is greater than that of any other. When the gas is consumed there may be about one-third of the heat saved, supposing the product to escape in the state of steam; but, where this steam can be condensed in such a manner as to render its heat effective, we shall gain the greatest effect with this kind of fuel.* Where we

* When the latent heat of gaseous bodies has been determined with precision for each gas, and also for the compound gases, we shall be able to anticipate the effect of a fuel with more certainty. We can easily perceive that most heat will be afforded by the combustion of a body in its gaseous state. Sir H. Davy made some experiments to determine the ratio of heat afforded by the combustion of gaseous bodies under the same circumstances. The effect was measured by the heat communicated to a quantity of olive oil in a given time, the oil being previously heated to 212°, to prevent any effect from the latent heat of the steam, generated during the combustion.

Olefiant gas raised the temperature of the oil	58 degrees.
Hydrogen	26
Sulphuretted hydrogen	20
Coal gas	14
Gaseous oxide of carbon	6

(New Researches on Flame, Philosophical Transactions, 1817,

have to employ a fuel containing only a small portion of hydrogen, it will be most economical to leave its consumption to chance, at least, so far as not to add a complex apparatus for obtaining its heat. And, on the whole, it appears very evident, that coal will rarely produce a greater effect than the coke that is formed from it, only when it is employed in the state of coal, the quantity of light gas produced gives a buoyancy to the smoke, which accelerates its motion and increases the draught; at the same time, the quantity of flame is greater,. and when the current is so directed as to force the flame against the surface to be heated, we obtain the effect of the fuel in a shorter time. It will be obvious that a fuel containing water, will lose so much of its effect as is necessary to convert that water into steam.

These remarks will afford the reader a tolerable idea of the advantage of particular kinds of coal; and will shew that those people are very little conversant with the subject, who suppose that the treatment and arrangement that has been successful in getting effect by one species, is also applicable to all others.

Wood.

27. In some places wood is used for fuel, its effect in producing heat is found to depend consi-

or Phil. Magazine, Vol. L. p. 7.) If the latent heat of the steam generated had been rendered effective, hydrogen would have been at the top of the scale, as it is in Mr. Dalton's experiments.

derably on its state of dryness. Several experiments made by Count Rumford, shew the effect of dry wood to be much greater than that of unseasoned.* Unseasoned wood contains about one-third of its weight of water; therefore the decrease of effect may be estimated by the principles given at the conclusion of the last article. The kind of wood is also a cause of some difference. From the experiments of Count Rumford, lime-tree gives out most heat in burning; as will be seen by the tables of this article.

A much larger space must be allowed for fuel in the construction of a fire-place for burning wood, than when coal is to be employed. And it is an advantage to have the wood cut into short pieces, particularly when a quick supply of heat is necessary.

With his improved boilers, Count Rumford made 20·10 lbs. of ice-cold water boil with 1 lb. of dry pine wood,† which is equivalent to heating one cubic foot of water one degree with ·0172 lbs.; therefore, 3·1 lbs. would boil a cubic foot of ice-cold water, or $2\frac{3}{4}$ lbs. would boil a cubic foot of water from the mean temperature; or it would require $19\frac{1}{4}$ lbs. of dry pine wood to boil off a cubic foot of water into steam, when the boiler is supplied by water at the mean temperature. The same measure of pine wood unseasoned, would produce less effect by one-seventh. A cubic foot of dry pine weighs about 34 lbs.

* Essays on Heat, &c. Vol. II. p. 88.

† Essays on Heat, Vol. II. p. 96.

Beech wood afforded much less heat than pine; for it required 1 lb. of dry beech to make 14·33 lbs. of ice-cold water boil,* or ·0242 lbs. to heat one cubic foot of water one degree; hence, it would require 4·36 lbs. to boil a cubic foot of ice-cold water, or nearly 3·9 lbs. if the water were at the mean temperature; consequently, about 27 lbs. would be necessary to boil off a cubic foot of water into steam, the water being supplied to the boiler at the mean temperature. A cubic foot of dry beech weighs about 44 lbs.

Oak, according to Hassenfratz,† affords rather more heat than pine, for his result is equivalent to a cubic foot of water being converted into steam by 18 lbs. of oak, perhaps from 25 to 30 lbs. is nearer the true average, as it must depend much on the quality of the wood.

According to Fossombroni, wood produces heat enough in its combustion to evaporate twice its weight of water, or to prepare two-thirds of its weight of salt.‡ Count Rumford's trials make the effect of wood about one-third more; which may fairly be attributed to his superior skill.

From several other experiments, made by Hassenfratz, on the heat developed by the combustion of different species of wood, the mean result was 40 lbs. of ice melted by 1 lb. of wood, which is equivalent to 62·5 lbs. of ice melted by 1·56 lbs. He tried 28 species of new and dry wood, the lowest result was

* Essays on Heat, Vol. II. page 96.

† Traité de l'Art du Charpentier, page 166.

‡ Dr. Young's Nat. Phil. Vol. II. p. 411.

32 lbs. of ice, and the highest 49 lbs of ice melted by 1 lb. of wood.* But from these experiments it would not do to estimate; because either a greater part of the heat given out by the wood has been confined to act upon the ice, than can be made to act upon a boiler, or the effect of the wood has been aided by other causes. Indeed, we know that it is more injurious than useful, to suffer the smoke of a furnace to be in contact with a boiler when its heat is less than that of boiling water, whereas, it would be effectual in melting ice, if kept in contact as long as possible. Hence, experiments on melting ice cannot be applied to determine the effect of fuel in generating steam. If experiments on melting ice shew the whole quantity of heat given out by a given quantity of fuel, it will follow, that we cannot estimate the useful effect in generating steam at more than half the actual quantity of heat given out.

Nevertheless, experiments on the quantity of ice melted by a given quantity of fuel will be useful in comparing the effects of different kinds.

28. The following Table contains the results of several experiments made by Count Rumford, on the heat which is given out during the combustion of different species of wood.† I have added two columns to shew the effect in generating steam and

* Dictionnaire de Physique, article Combustion, Encyc. Méthodique.

† Dr. Thomson's System of Chemistry, Vol. I. p. 149, fifth edition.

boiling water, on the supposition that only half the heat is effective in these operations which can be rendered so in melting ice.

Species of Wood.	State when tried.	Pounds of fuel to melt 62·5 lbs of ice.	Pounds of fuel to boil a cub. f. of water from the mean tem.	Pounds of fuel to convert a cub. ft. of water into steam from the mean tem.
		lbs.	lbs.	lbs.
Lime tree.	Joiner's dry wood, 4 years old....	1·35	3·10	22
Ditto.	Ditto highly dried on a chafing dish	1·18	2·70	19·4
Beech.	Joiner's dry wood, 4 or 5 years old	1·38	3·16	22·6
Elm.	Ditto	1·54	3·52	25·5
Oak.	Common firewood in chips	1·83	4·20	30·0
Ash.	Joiner's dry wood	1 53	3·50	25·2
Maple.	Seasoned wood, highly dried over a chafing dish......	1·30	3·00	21·4
Service tree.	Ditto. Ditto	1 31	3·00	25·5
Cherry tree.	Joiner's dry wood	1·40	3·20	23·0
Fir.	Ditto	1·54	3·52	25·5
Poplar.	Ditto	1·35	3·10	22·0
Hornbeam.	Ditto	1·47	3·37	24·0
Oak.	With 19·5 per cent. of water, combustion not perfect ..	1 78	4·10	29·2

On these experiments it is necessary to remark, that the age of the trees would be a cause of considerable difference in experiments on the same species of wood. If the numbers of the last column of the table be compared with those derived from Count Rumford's experiments in art. 27. it will be found that they nearly agree; and in the quantity of ice melted by a given quantity of wood, they nearly coincide with the experiments of Hassenfratz.

Peat.

29. The quality of peat varies according to the different situations where it is formed; as these places differ in drainage; in the nature of the vege-

tables they produce; and in the kind and quantity of alluvium deposited among the dead vegetable matter. The specific gravity of peat varies considerably, and when it is free from gravel, its quality as a fuel depends much on its density. In several instances, it is so dense as to sink in water, and so compact as to afford a flaming fuel little inferior to some kinds of coal. The whole of the varieties, Dr. M'Culloch, in an interesting paper on this subject,* has considered to be included in the following divisions; viz. Mountain peat, Marsh peat, Lake peat, Forest peat, and Marine peat: of these the mountain peat is of least value for fuel, being of a loose texture, and the average thickness not above one foot.

Peat, considered only as a fuel, may be divided into two kinds. The first is compact and heavy, of a brownish black colour, and with scarcely any vestiges of its vegetable origin remaining. This is the best kind. When it has been lighted it preserves fire a long time.

The second kind is light and spongy, of a brown colour, and seems to be a mass of dead plants and roots which have undergone very little change; it inflames readily, and is quickly consumed.

Peat gives out an odour while it is burning, which is disagreeable to those who are not accustomed to it. It affords a mild and gentle heat, but is not a good kind of fuel for supplying furnaces for boilers; it

* Edinburgh Phil. Journal, Vol. II. p. 40, where Dr. M'Culloch has given lists of the plants which chiefly contribute to form peat of the different kinds. See also his Description of the Western Islands of Scotland, Vol. I. 127.

is much better adapted for flues. It is of various qualities; some burn quickly, with a bright flame; others burn slowly, and according to Clément and Desormes, afford one-fifth of the heat that would be given out by an equal weight of charcoal,* which nearly coincides with the ratio given by Blavier and Miché; therefore, about 53·6lbs. of good peat would be required to convert a cubic foot of water into steam from the mean temperature, or it will convert 7-6ths of its own weight of water into steam. The labour and expense of drying peat is very considerable, and this labour is required to be done at a season which is usually not very convenient: for it is at a time when there is full employment in farming business. The time might be shortened by subjecting the peat to pressure, as proposed by Dr. Lind, so as to expel the moisture; and this pressure would render it more compact and durable as fuel. Bramah's press might be applied with much advantage to this purpose. The time might also be reduced by applying artificial heat; one portion being applied as fuel to convert a larger portion into fuel fit for use; a process which could be carried on in winter. (See Chap. XI.) The weight of a cubic foot varies from 44 to 70lbs., and the dense varieties afford about 40 per cent. of charcoal; the other varieties nearly in proportion to their density.

Charred Fuel.

30. *Charcoal.*—The slow and regular heat af-

* Dictionnaire de Physique, Tome II. p. 475.

forded by fuel which has been previously charred is of great advantage where a steam apparatus is not connected with the boiler of a steam engine, because it renders less attention necessary. The experiments on this kind of fuel are very discordant, and I must select from them.

Mr. Dalton, by heating water, obtained a result equivalent to melting 40lbs. of ice with one pound of charcoal. But Dr. Crawford's experiments give 69lbs. of ice melted by 1lb. of charcoal.* Lavoisier's give $95\frac{1}{2}$lbs., Clément and Desormes 95lbs., and Hassenfratz's trials, on various kinds, give a mean of 92lbs. of ice melted by 1 lb. of charcoal; his highest result being 96lbs., and lowest one 74lbs.† But since the experiments by melting ice give about double the true quantity (see art. 27.) that can be effectively applied, we may assume 47lbs. of ice melted by 1 lb. of charcoal as the measure of effect. Therefore, 0·0095lbs. of charcoal will heat one cubic foot of water one degree; or 1·52lbs. will be required to boil a cubic foot of water from the mean temperature of 52°; or $10\frac{2}{3}$lbs. will be necessary to convert a cubic foot of water into steam from the mean temperature, or about 6 times its own weight of water into steam.

31. *Coke.*—Lavoisier makes the quantity of coal to be to that of coke as 605 is to 552,‡ when the

* Dr. Thomson's Chemistry, Vol. I. p. 148.

† Dictionnaire de Physique, art. Combustion. Encyc. Méthod.

‡ Idem. Kirwan's table, quoted from Lavoisier, is certainly inaccurate, both in weight and measure.

same effect is produced. Whence 0·0069lbs. of coke will raise the temperature of one cubic foot of water one degree: or 1·1 lbs. will boil a cubic foot of water from the mean temperature; or 7·7lbs. will convert a cubic foot of water into steam from the mean temperature, which is nearly equal to converting eight times its own weight into steam.

32. *Charred Peat.*—According to Blavier and Miché,* the quantities of charcoal and charred peat are 740 and 1666 respectively to produce the same effect; therefore, if the quantity of charcoal which will produce a given effect be multiplied by 2·16, we shall have the equivalent quantity of charred peat. From this we find, that 23lbs. of charred peat will convert a cubic foot of water into steam from the mean temperature; or it will convert nearly 3 times its weight of water into steam. The peat charred by distillation is esteemed much superior to that charred by stifling.

33. A collected view of the data from these experiments and comparisons, is given in the first Table at the end of this treatise, so as to afford the readiest means of taking them for practice, or of comparing them for information on the comparative expense of different kinds of fuel. In closing this inquiry, it will appear that the utmost effect we can hope to gain in appplying fuel, must be less than double the measures of effect here given; and even

* Dictionnaire de Physique, art. Combustion. Encyc. Méthod.

to attain that effect, all the caution of conducting a philosophical experiment must be continually employed, which will be found impracticable on a large scale, and altogether incompatible with the simple apparatus and small share of attention which can be devoted to this end in real business. But nothing less than such an investigation was necessary to stem the torrent of quackery, which promises 4, 6, and even 10 times these effects. I have chosen to rest my evidence chiefly on the experiments of others; for the variable qualities of fuel render it difficult to add any thing at once novel and useful, unless such experiments were accompanied by a chemical analysis of each of the substances employed.

CHAPTER III.

OF THE EFFECT OF STEAM IN DISTRIBUTNG HEAT, AND THE EXPENDITURE OF FUEL TO PRODUCE A GIVEN EFFECT.

"The true method of improving the arts, consists less in describing their processes with accuracy, than in bringing all their operations to general principles." CHAPTAL.

34. THE object of this chapter is chiefly to determine the quantity of steam that will be necessary to heat a given bulk of air; and the proportion of surface of steam vessel or pipe, that will afford any proposed degree of heat in a given time.

The usual rules adopted by practical writers are very erroneous; they are so much so indeed, that only exactly similar cases can be regulated by them. The ratio of heat to the space has to be varied six, eight, or even ten times, to accommodate it to a building which differs from the one to which it was first applied; and yet there has been no method of regulating the proportion of heat to the nature of the space to be heated, except by trial; which affords no rule when the cases are not perfectly similar.

The quantity of heat has been hitherto proportioned by the cubic feet of space to be heated: a superficial foot of steam-pipe, it is said, will heat about 200 cubic feet of space, or a cubic foot of

boiler 2000 feet of space.* The stove of one of Messrs. Strutt's cotton-mills is said to warm 266,247 cubic feet of space to 60°, when the external air is at 35°, by a consumption of 184 lbs. of coal in 12 hours, when the fire is continued night and day.† These proportions are given for cotton-mills, but they are perfectly useless in any instance where a different degree of ventilation is necessary, as in hospitals, —where a greater proportion of window is necessary, as in houses for plants,‡—and, even in the case for which they are given, they afford us no means of knowing the degree of ventilation which will be obtained by adhering to these proportions.

The scientific principles of the subject have been ably discussed, and have been long in the hands of the public, they only require application; and, if I can succeed in making the application in a clear and simple manner, I hope it will be found useful to those engaged in the management of heat, and enable them to proceed on such certain principles as must be highly beneficial to the public.

35. We have two direct causes of loss of heat in all cases: the one is the cooling effect of the

* Buchanan's Essays on Heating Buildings by Steam, 1810, pp. 160 and 162.

† Sylvester's Philosophy of Domestic Economy, p. 15.

‡ This erroneous rule has also an effect on the art of designing for such houses; for the prime object is considered to be to reduce the space to be heated, under the impression that the consumption of fuel is in proportion to the quantity of air a house contains. (See Serre chaude, p. 314, Dict. Agriculture, Encyc. Méthod.)

external air against the windows, and other external surfaces of the building;—the other is the quantity conveyed away by the impure air, which must be removed by ventilation, the outlets by crevices, &c. Both these causes of loss of heat must depend on the nature of the building, or the purpose it is intended for; and the total amount of the loss in different cases will be shewn in the next chapter. But it will always be measured by a certain quantity of air heated to the temperature of the room, from that of the external air; and, therefore, the fuel, or the surface of steam-vessel that will be sufficient to heat that quantity of air, will sustain the room at the proposed temperature.

36. We shall have also to determine the quantity of fuel which will warm the walls and raise the temperature of the whole mass of air in the room to the required temperature in the first instance, but this is of less importance; and to arrive at any very accurate conclusions will involve us in a more intricate inquiry than it is here proposed to enter into. But as the effect will be equivalent to heating a certain quantity of air to the required temperature, it may be made a particular case of the general inquiry.

I shall here state the principles on which the investigation will be conducted: but it should be remarked, that the principles are general; that is, what is here stated respecting steam-pipes is equally true of any other surface, confining any other hot fluid, when it is exposed to cool in the same medium. For example, heated air confined by a surface of glass

in a hot-house, gives off heat according to the same laws as a pipe containing steam. But general laws are most easily studied in their application to a particular case, because the mind seldom gains a clear conception of such laws till they be applied; and, consequently, when they are referred to a case in question at the outset, the subject is brought in a more simple form before the reader, and he has not of himself to look round for any thing to illustrate it.

Laws of Cooling.

37. When pipes, or other vessels of inconsiderable thickness, are filled with steam, the effect of the heat will be obviously constant, when the pipes are the same, and the excess of temperature is the same: that is, the quantity of heat given off will, in this case, be equal in equal times.

38. But, the pipes or vessels being the same, if the temperature of the air to be heated, or if the surface giving off heat, be different at different times, the heat given off in a given portion of time will be directly as the excess of temperature of surface of the body giving off heat;* in gaseous media, or in any fluid which is kept in motion.

* This law of cooling is simple and nearly accurate: it was first announced by Sir Isaac Newton. (See Philosophical Transactions, 1701, or Principles of Natural Philosophy, Vol. II. Prop. XLI.) It was supposed to be erroneous by Dr. Martine, in 1730, but it was verified for low temperatures by Krafft and Richmann, (Thomson's Chemistry, Vol. I. p. 58; and Young's Nat. Phil. Vol. II. p. 404,)

39. Also, if the substance used for pipes or vessels to contain steam be varied, the quantity of heat given off will be different; as has been shewn by the experiments of Professor Leslie,* and Dulong and Petit.†

40. But, it is also obvious, that the quantity of heat given off in a given time will be directly as the surface,‡ when the pipes are of similar figures, but not otherwise; because the action of the steam is not equal on every part of the surface of a pipe,

and similar experiments have been since repeated by Professor Leslie, (Inquiry, Chap. XIV.) Dalton, and others; and all of which seem to prove, satisfactorily enough, that within the range of 180° of difference of temperature, the law may be considered correct. But Dulong and Petit have lately made a laborious set of experiments on the laws of cooling; from which it would appear, that, with a greater difference of temperature, this law becomes inaccurate. It does not, however, appear to me, after a careful examination of their memoir, that they have avoided all sources of error in treating this delicate subject; for it does not appear possible, with a complicated apparatus, to obtain the rate of cooling free from the effect of the conducting power of the apparatus, which would have considerable effect when the temperature of the hot body greatly exceeded that of the surrounding ones. (A translation of the memoir will be found in Dr. Thomson's Annals of Philosophy, Vol. XIII.) But even these researches shew, that Newton's law is accurate enough for practice. If the heat were given off to any other fluid or gaseous medium than air, there would be a difference of effect. From the experiments of Sir H. Davy, it appears that bodies cool more rapidly in hydrogen than in other gases. (Researches on Flame, Phil. Trans. 1817.)

* Inquiry into Nature of Heat, Chap. XIV. &c.

† Annals of Phil. XIII. 177.

‡ Idem, 178.

the upper part of the pipe being always hotter than the lower part. And the same variation will take place when other fluids are confined, but in a less degree. It will, however, be sufficiently accurate for our purpose, to consider the effect to be proportional to the surface. According to some observations I have made on the heat of the under side of a steam-pipe, it appears to be about 180°; hence, the mean heat will not be more than 200°, when steam is worked at the temperature of 220°, or 2½lbs. upon a square inch above the pressure of the atmosphere.

41. Writers on heat usually denote the specific heat of water by unity; hence, we may conveniently express the effect of a pipe by the number of degrees a given surface of it would heat a cubic foot of water; and then the quantity of any other body in cubic feet, that would be heated the same number of degrees, will be the reciprocal of its specific heat, or the denominator of the fraction which expresses the specific heat. Thus, it will require the same surface to heat 2850 cubic feet of air one degree, as to heat one cubic foot of water one degree. (See art. 20.)

Experiments on Cooling, or the Effect of Surfaces in giving off Heat.

42. In trying experiments on cooling, I could not conveniently employ steam, because it does not afford the means of obtaining a very accurate measure of effect. I therefore used hot water, and my

method was simple and easily repeated: it consisted in filling a cylinder with hot water, and observing the rate of cooling, so as to have two measures of effect; the one given directly by observation, the other calculated by the law of cooling.

The cylinders were of wrought iron, tinned iron, and glass, and as nearly of the same size and form as I could obtain them. (See Fig. 15, Plate IV.) The same top fitted all the cylinders: it was formed of tin, and covered, to about an inch in thickness, with alternate folds of cotton and flannel; so that the loss of heat might be regarded as insensible. Through the top the naked stem of the thermometer T passed, so as just to shew the 150th degree; the bulb of the thermometer was then at half the height of the cylinder, and within about a quarter of an inch of the side of the cylinder, as at A. The thermometer had the degrees graduated on the glass stem, and the cylinders were suspended by loosely twisted cotton thread, *C*, *C*, *C*, to prevent loss of heat by conduction. The effect in giving off heat is obviously equal to the quantity of water cooled, the observed number of degrees in a minute.* To be able to make direct observations on this point, after filling the cylinder with boiling water, and adjusting the cover and thermometer, I waited till the

* If c be the number of cubic inches of water used in the experiment, and n the number of degrees cooled in a minute, then $\frac{cn}{1728}=\acute{\varepsilon}$, the effect, as used in the following note; also $s'=\frac{b}{144}$ where b is the surface in inches, or $\frac{\acute{\varepsilon}}{s'}=\frac{cn}{12b}$.

thermometer was at 181°, and then counted the seconds till it was at 180° and 179°. The time of descending from 180° to 150° was also observed. The specific heat of the cylinder was allowed for, by adding its equivalent to the cubic inches of water.

1*st Experiment.*—With a tinned iron cylinder, very slightly tarnished, the surface 79 square inches, and the quantity of water added to the equivalent of specific heat of the cylinder 62·28 cubic inches. Temperature of the room not varying $\frac{1}{4}$ of a degree from $55\frac{1}{2}°$ during the trial. It cooled from 181° to 179° in 158 seconds; whence we may infer, that the loss of heat is 0·76° per minute when the excess of temperature is 180 — 55·5 = 124·5°.

The time of cooling from 180° to 150° was 46 minutes; from whence we find the loss per minute 0·759° when the excess of temperature is 124·5°;* the two modes of observing afford very nearly the same result; and the constant number derived from them is 0·0004.†

* Let D be the difference of temperature at the commencement of the observation, d the difference at the expiration of t minutes, and mD the heat lost in the first minute; then $D(1-m)^t = d$. (Playfair's Outlines of Nat. Phil. Vol. I. art. 313.) Or, $1-\left(\frac{d}{D}\right)^{\frac{1}{t}} = m$. Whence, mD is easily found with the assistance of a table of logarithms. In the case above, D=124·5°, and d=150—55·5 =94·5°, and t=46 minutes: which gives m = 0·0061, or mD =0·75945.

† Let T be the temperature of the body giving out heat, and t the temperature of the medium which surrounds it.

In another trial the constant number was nearly 0·00043, and the mean of three trials is nearly 0·00041.

2nd Experiment.—Made with a glass cylinder, of which the surface was 71 square inches, and the quantity of water, added to the quantity equivalent to the specific heat of the cylinder, 61·2 cubic inches, the temperature of the room $56\frac{1}{2}°$ during the experiment.

It cooled from 181° to 179° in 109 seconds; which makes the loss of heat 1·1° per minute when the excess of temperature is $180 - 56\frac{1}{2} = 123·5$.

Also, let s be the quantity of surface, and ε the number of degrees a cubic foot of water would be heated by the heat given off. Make the same letters *accented* denote the same things in the experiments. Then, the quantity of heat given off in one minute, being directly as the surface, and as the difference of temperature, $s'(T'-t') : \varepsilon' :: s(T-t) : \varepsilon = \frac{\varepsilon' s(T-t)}{s'(T'-t')}$, and since by the preceding note $\frac{\varepsilon'}{s'} = \frac{cn}{12b'}$, we have $\frac{cns(T-t)}{12b(T'-t')} = \varepsilon$. When the body giving out heat is contained in a tin vessel, not much tarnished, but as it would be after being some time in use, then $0·00041\, s\,(T-t) = \varepsilon =$ the number of degrees a cubic foot of water would be heated in one minute.

When the body giving off heat is contained by a glass vessel, then, experiment gives $0·000644\, s\,(T-t) = \varepsilon =$ the number of degrees a cubic foot of water would be heated in one minute.

When the body giving out heat is contained in a vessel of iron, $0·000738\, s\,(T-t) = \varepsilon =$ the number of degrees a cubic foot of water would be heated in one minute.

The same formulæ apply to ascertain the loss of heat for a room, maintained at a greater temperature than the external air; and then 2850 cubic feet of air will be heated ε degrees.

The time of cooling from 180° to 150° was 31$\frac{1}{7}$ minutes, which gives the loss of heat 1·075° per minute, when the excess of temperature is 123·5°. Here again the results of the two methods agree very well.

The constant number calculated from this experiment is 0·000644, a second trial gave 0·000615, and a third 0·00066; and as 0·000644 is nearly the mean, and was made with the temperature of the room most uniform, it shall be made the basis of the rules.

3rd *Experiment.*—In this experiment, a wrought iron cylinder was used, the iron with a black surface, as sheet iron is received from the manufacturer. The quantity of surface was 76·7 inches, and the quantity of water added to a quantity equivalent to the specific heat of the cylinder was 61·7 cubic inches. The temperature of the room during the experiment was 57.°

It cooled from 181° to 179° in 101 seconds; which makes the loss of heat per minute very nearly 1·2°, when the excess of temperature is 180° − 57° = 123°.

It cooled from 180° to 150° in 29 minutes, and, consequently, the loss of heat is 1·18° per minute when the excess of temperature is 123°. The constant number calculated from this experiment is 0·000656. I had not time to repeat the trials till a few days after the first was done; and, on examining my cylinder, I found all the black scale broken up; and it presented a rusty brown surface when the loose matter was rubbed off. In this state, the

mean of two trials gave 0·000738 for the constant number; and as the surface in this state is nearer to that of cast-iron pipes than the smooth black one, I have taken the constant 0·000738 for the rules.

The comparative effect of the different surfaces will be, according to these trials,—

Tinned iron	100
Glass	155
Sheet iron with a smooth black scale upon it	156
Sheet iron with a rusty brown surface	180

From data thus ascertained, the quantity of surface of steam pipe, &c. that will maintain a room at a given temperature, is easily calculated; the degree of ventilation and the loss of heat being previously estimated, as pointed out in the chapter on these subjects. (See Chap. IV.)

43. To make this calculation, the temperature of the external air, or of the air that supplies the ventilation, is to be known at the extreme case of cold, which, for the day may be taken at 30°, but for night, may generally be assumed, at once, to be at zero of Fahrenheit's thermometer, as the cold is seldom more intense in this climate. The temperature at which it is proposed to maintain the room or place to be heated at the same season of cold is also to be settled, and the quantity of air per minute which should be raised from the temperature of the external air to that of the room, in order to supply the loss of heat and ventilation. (See art. 68, 70.) It has been observed, that the mean temperature of

the surface of the pipe containing the steam, at the ordinary pressure is 200°. (art. 40.)

44. Rule.—Multiply the cubic feet, per minute, of air to be heated, to supply the ventilation and loss of heat, by the difference between the temperature the room is to be kept at, and that of the external air, in degrees of Fahrenheit's thermometer, and divide the product by 2·1 times the difference between 200 and the temperature of the room: this quotient will give the quantity of surface of cast iron steam-pipe that will be sufficient to maintain the room at the required temperature.*

* We have found (in the note to art. 42,) that, when a is put for the constant number, $a\,s\,(\mathrm{T}-t) = \varepsilon$, when 2850 cubic feet of air is raised ε degrees in one minute. Now, in our present case t must be the temperature of the room, and ε must be the difference between this temperature and that of the external air, or $\varepsilon = t - t'$, where t' is the temperature of the external air. Consequently,

$$a\,s\,(\mathrm{T}-t) = t - t', \text{ or } s = \frac{t-t'}{a\,(\mathrm{T}-t)}.$$

And if A be taken to represent the number of cubic feet of air to be heated per minute, to supply the loss of heat, we shall have

$$s = \frac{\mathrm{A}\,(t-t')}{2850\,a\,(\mathrm{T}-t)}.$$

When s is the quantity of surface of pipe in feet that would heat the quantity A cubic feet of air per minute, to $t-t'$ degrees of Fahrenheit's thermometer.

When the pipes are of cast iron, $a = \cdot 000738$, and we have

$$s = \frac{\mathrm{A}\,(t-t')}{2\cdot 1\,(\mathrm{T}-t)}.$$

In the rule in the text $\mathrm{T} = 200$, consequently

$$s = \frac{\mathrm{A}\,(t-t')}{2\cdot 1\,(200-t)};$$

which is the same as the rule.

This rule is applicable to all cases of heating by steam, when iron is used for pipes; and particular examples will be found in the chapters devoted to the particular kinds of rooms or places usually heated by steam.

45. In the next place we have to inquire what expenditure of fuel will afford heat for a given surface of pipe. By this means, we can know the quantity expended, when the greatest effect is to be produced, and also estimate the mean quantity a season will require, but with less accuracy, because it depends on the state of the weather. For the latter purpose, the mean temperature should be taken from observations confined to the season in which artificial heat is necessary; and the mean duration of that season should be determined from observations continued several years. In a few cases, I shall make some calculations of this kind, where a previous estimate of the expense is likely to be useful; for, though they will not be accurate for any particular year, they will be near to the average of several years; and perhaps many of my readers may be able to calculate from more accurate knowledge of the mean temperature, and of the time fire-heat is required: mine are drawn from the meteorological tables.

46. If the condensed water returns to the boiler, without loss of heat, the same quantity of fuel that would make a cubic foot of water boil from the mean temperature, would be sufficient to afford heat

to 26 feet of surface of cast iron steam-pipe for one hour, when the temperature of the room is to be maintained at 60°,* and supposing the water to be supplied to the boiler at 52°, then (by art. 19) 7 × 26 = 182 feet of surface of steam-pipe will condense a cubic foot of water per hour.

47. If the room is to be kept at 80°, the same quantity of fuel will afford heat for supplying 30 feet of surface of steam-pipe for one hour, and 210 feet of pipe will condense a cubic foot of water in the same time, if the boiler be supplied at 52°.

48. And when the room is to be kept at 100°, the same quantity of fuel will supply 36 feet of surface of pipe for an hour, and 252 feet of pipe will condense a cubic foot of water in the same time.

49. The quantity of coal per hour, necessary to produce this effect, we have found to be 1·2 lbs. (art. 23.) But 1·2 lbs. is the 1-70th part of a bushel; therefore, a bushel of Newcastle coals per hour, will

* In a former note (art. 42,) the relation between the surface of steam-pipe, and the heat given off is found to be $\cdot 000738\, s\, (T - t) = \varepsilon$; and, if we make $\varepsilon = 160°$, then $\cdot 000738\, s\, (T - t) = 160°$, in which case s is the surface of steam-pipe that would heat a cubic foot of water 160°, or make it boil from the mean temperature. But we have taken T, the mean heat of the surface of the pipe at 200°, and the time is to be one hour; hence, the equation becomes $s = \frac{3610}{(200 - t)}$, where s is the surface of steam-pipe, and t the temperature of the room; and putting $t = 60°$ we have $s = 26$: and so of any other temperature.

supply heat to 1820 feet of surface of pipe in a room at 60°,

2100 ditto, ... at 80°,
2520 ditto, ... at 100°.

If the condensed water cannot be returned to the boiler, about 1-12th of the heat will be lost; and consequently, these quantities of surface must be reduced by 1-12th.

In addition, there will be required as much fuel as will supply the waste of heat at the boiler; and if no means are employed to prevent loss of heat at its surface, it must be measured and considered as part of the above quantity of surface of steam-pipe. But if the surface of the boiler be exposed in an open shed, or in any place where the air is cooler than in the place which is warmed by the pipes, a separate calculation must be made for loss of heat at the boiler. In such cases, the loss of heat at the boiler will often be equal to the effect of the steam-pipes it supplies, and in small boilers the proportion of loss will be greatest: therefore, we need not be surprised at the extravagant and ineffectual consumption of fuel in many cases where steam has been applied. *A boiler which has 70 feet of surface, exposed in an open shed, at the temperature of 32°, will waste a bushel of coals in 24 hours.*

50. When the surface of steam-pipe is proportioned so as to produce the desired effect, (by art. 44,) we have an easy mode of knowing the fuel that will keep up the supply of steam by the preceding

article. (art. 49.) Because, if the whole quantity of exposed surface of steam-pipe be taken in superficial feet, and divided by 1820, it will give the number of bushels or parts of a bushel that will be required for one hour, when the temperature of the place is to be sustained at 60°.

If the temperature is to be maintained at 80°, divide by 2100.

And, if it is to be maintained at 100°, divide by 2520.

Example.—A room is kept at 100° by 580 feet of steam-pipe, what quantity of Newcastle coal will supply the pipes 10 hours? Here $\frac{580}{2520} = \cdot 23$ bushels will serve one hour, and, therefore, $2\frac{3}{10}$ bushels will supply the pipes 10 hours.

51. It will be necessary to know the quantity of water that will be condensed in a given time, particularly where the condensed water is not, or cannot, be returned to the boiler, because then the supply of water can be regulated.

Now, I have shewn (in art. 46, 47, and 48,) the quantity of surface of steam-pipe that will condense a cubic foot of water at different temperatures; and, when the whole quantity of surface is known, let it be divided by the surface that will condense one cubic foot, and the result will be the quantity of water required in cubic feet.*

52. To estimate the expenditure of fuel for a

* A cubic foot of water is very nearly $6\frac{1}{8}$ gallons, ale measure.

season, we must divide the subject into particular cases, and the calculation will be most easily managed by taking the quantity of air to be heated. The distinct cases will be, 1*st*, When the fires are kept on constantly during the season. 2*dly*, When the fire is kept on only a certain number of hours in the day.

53. When the fire is to be kept on constantly during the season, then the quantity of air to be heated, will be equal to that necessary to supply the ventilation and loss of heat: the manner of determining this quantity is shewn in art. 68, 70, &c. It is there to be found in cubic feet per minute, and there are 1440 minutes in a day; hence, 1440 times that number of cubic feet will be the daily quantity of air to be warmed.

If the place is to be kept at a temperature of 56°, the average number of days artificial heat will be necessary is about 220 in the neighbourhood of London, and $220 \times 1440 = 316{,}800$.

The mean temperature of the 220 days is about 40° for near London; and, consequently, the mean elevation of temperature to be produced is $56 - 40 = 16$ degrees. Therefore, multiply 16 by 316,800, and we have 5,068,800 times the quantity of air that would supply the ventilation and loss of heat one minute, to be heated one degree to supply the season. But, ·00000262 lbs. of Newcastle coal will heat a cubic foot of air one degree, (art. 23;) and 84 lbs. is a bushel; hence, we may estimate, in this case, the consumption of a season in bushels, at one-

sixth of quantity of air in cubic feet that would supply the ventilation and loss of heat one minute,* a proportion that will be easily remembered.

If the temperature is to be kept at 60°, then, near London, artificial heat will, on an average, be required for 260 days, and the number of bushels will be about ·21 times the number of cubic feet of air that would supply the ventilation and loss of heat one minute.

The same mode of calculation will be applicable to forcing-houses for plants: see the chapter on that subject.

54. When a fire heat is wanted only for a certain number of hours in a day, the whole of the air in the apartment will have to be warmed in the morn-

* For the advantage of readers that do not calculate by algebraic notation, I have gone through the above example, but we may here make it general. Let D be the number of days artificial heat is necessary, t' the mean temperature of that period, and t the temperature the place is to be sustained at. Also, let f be the quantity of fuel in lbs. that will heat one cubic foot of air one degree, A the cubic feet of air to be heated every minute, h the number of hours the heat is to be continued, and F the quantity of fuel for the season.

Then, $60AhD\,(t-t')\,f = F$ in lbs.

Or, for coals, $\dfrac{60\,A\,h\,D\,f\,(t-t')}{84} = \dfrac{A\,h\,D\,f\,(t-t')}{1{\cdot}4} = F$ in bushels.

When Newcastle coal is employed, $f = {\cdot}00000262$.

$$0{\cdot}00000187\,A\,h\,D\,(t-t') = F \text{ in bushels.}$$

And, when $h=24$; $D=220$; and $t-t'=16$ as in the text

$$0{\cdot}158\,A = F \text{ in bushels,}$$

Or, with sufficient accuracy, $\dfrac{A}{6} = F$ bushels.

ing, as well as the pipes, boiler, and the solid parts of the room. We shall be able to ascertain the quantity most easily by assigning the number of additional hours the apparatus should be in action to raise the temperature, if it were continued at the same intensity as would be necessary during the rest of the day; and in other respects, the calculation may be conducted in the same manner as in the case where the heat is kept up night and day.

But it should be observed, that the mean day heat will be somewhat greater than that of night and day: the difference is not such as need be regarded in inquiries of this kind, where a view of the annual expense of an average year is the only object of research.

CHAPTER IV.

OF VENTILATION, AND THE CAUSES OF LOSS OF HEAT.

"The air inhaled is not the gas
That from a thousand lungs reeks back to thine,
Sated with exhalations rank and fell;
Which, drank, would poison the balsamic blood,
And rouse the heart to ev'ry fever's rage—
But air that trembling floats from hill to hill,
From vale to mountain, with incessant change
Of purest element." ARMSTRONG.

55. In any place warmed by artificial heat, it is desirable, on principles of economy, that a greater portion of heated air should not escape than is requisite to preserve a pure atmosphere to breathe in; but it is of greater importance to preserve the air pure and wholesome, than that a small portion of heat should be lost. It has been made so important an object to save fuel, by most of the speculators on heating rooms, that the means of ventilation have not always been duly considered, and the most invaluable of human blessings—health—has, I am fearful, been too frequently trifled with, to save an inconsiderable expenditure of fuel.

Now, having no bias in favour of any particular mode of applying heat,* I take up the sub-

* If I had only one particular scheme, of course there would be a motive to make it appear economical, when compared with others;

ject in the search of truth, and with a desire to do the utmost in my power for the public welfare; and, as the subject is intimately connected with the well-being of a very numerous portion of the community, I trust my researches will be useful.

That a pure atmosphere is necessary to preserve health I need not attempt to prove by reasoning; it is a truth universally known and acknowledged: but it will be proper to examine and estimate the effect of those causes which render confined air impure and unfit for supporting life. It has been remarked, that "the salubrity and healthy state of the air depend, in a great measure, on the quantity of oxygen gas it contains, and this quantity appears to exist in all places exposed to a free atmosphere, and the influence of winds. But the same uniformity of composition does not prevail in the confined air of dwelling houses, crowded theatres, and hospitals that are badly ventilated."* Yet, the chemist who wrote this remark was not able to detect an appreciable difference between the air of an hospital and that of an open situation. And the same thing is averred by other chemists. Seguin tried the air of an hospital, the odour of which was disagreeable, but it gave him the same result as the external air. The researches of Priestley, De Marti, Gay Lussac, and others, all tend to establish the same result; which is, that the composition of the atmosphere is

and either to leave its ventilation unconsidered, or be content to see it neglected.

* Philosophical Mag. Vol. L. p. 433.

essentially the same every where.* If you allow these experiments to be correct, they only prove that a deadly poison may be diffused through the atmosphere which the art of the chemist cannot detect, but of which we have better evidence than is given by the nicest tests of the analytical chemist, in the pale visages and weakly constitutions of the inhabitants of confined and crowded cities; in the unhealthiness of particular districts, and in the important alteration which a change of residence often produces in individuals unaccustomed to such changes. If there be no variation in the quantity of oxygen, some other means should be taken to enable us to know what the difference consists in. Perhaps it is the presence of foreign ingredients: these should be tested for. The atmosphere in the neighbourhood of the sea is said to contain muriatic acid. The subject is too interesting to remain at a stand; and if it were once entered upon with a Wollaston's delicacy of analysis, we might expect much important information.

Of the Ventilation and Loss of Heat in Public Buildings and Dwelling Houses.

56. *Ventilation.*—The physiological chemists have placed in our hands a more accurate means of measuring the deterioration of air in dwelling rooms, than by the best eudiometer; for they have shewn, by repeated experiments on respiration, that

* Dr. Murray's System of Chemistry, Vol. II. p. 37. Dr. Thomson's System of Chemistry, Vol. III. p. 178.

a man consumes about 32 cubic inches of oxygen in a minute, which is replaced by an equal bulk of carbonic acid gas from the lungs.* Now, the quantity of oxygen in atmospheric air is about one-fifth; hence it will be found that the quantity rendered unfit for supporting either combustion or animal life, by one man in one minute, is nearly 160 cubic inches by respiration only. But a man makes 20 respirations in a minute, and draws in and expels 40 inches of air at each respiration; consequently, the total quantity contaminated in one minute, by passing through the lungs, is 800 cubic inches.

57. During the same time a man discharges a considerable quantity of vapour from the lungs. The experiments on this subject afforded results which differ considerably; it must be best to take the highest probable result, which makes it 6 grains per minute.† It will not exceed this, because $6\frac{1}{2}$ grains would saturate 800 cubic inches of air at the

* A collected view of these experiments is given by Dr. Thomson, System of Chemistry, Vol. IV. p. 615; by Dr. Murray, System of Chemistry, Vol. IV. p. 491. From the experiments of Dr. Prout and Dr. Fyfe, it appears that the quantity of carbonic acid gas emitted is different at different periods of the day, and according to the nature of the diet: the quantity is least in the night. (See Dr. Thomson's Annals, Vol. IV. p. 331.)

† The experiments of Dr. Hales make it nearly seven grains per minute, Dr. Thomson six grains. (Syst. of Chem. Vol. IV. p. 621.) Dr. Murray and Mr. Abernethy, three grains, (Murray's Chem. Vol. IV. p. 497.) Lavoisier and Seguin make it a little more than seven grains per minute. (Dict. de Chimie; art. Transpiration, Encyc. Méthod.)

temperature it is given out at in respiration, and it will probably be seldom less. If the air from the lungs did not contain this mixture of vapour, it would not rise when expelled; and we have here to admire one of those simple and beautiful arrangements, by which our all-wise Creator has provided against the repeated inhalation of the same air: for a mixture of azote, carbonic acid gas, and vapour, at the temperature it is ejected, is much lighter than common air even at the same temperature. Hence, it rises with such velocity, that it is entirely removed from us before it becomes diffused in the atmosphere.

58. But, as all gaseous bodies and vapours intimately mix when suffered to remain in contact, we see how important it is that ventilation should be continual; that the noxious gases should be expelled as soon as they are generated; that the ventilation should be from the upper part of a room; and that the fresh air should not enter where it is, in any degree, liable to mix with that which has risen from the lungs.

59. There are other causes of impurity to be considered, for it appears that a man gives off by insensible perspiration from 12 to 30 grains of vapour per minute;* and it has also been observed, that air which has been sometime in contact with the skin, becomes chiefly carbonic acid gas. The

* Lavoisier and Seguin found it fifteen grains per minute.

absolute quantity of air rendered unfit for respiration by these causes, does not appear to have been ascertained. It must, at least, be desirable to change as much of the air of a room as the moisture given off would saturate in the same time; and in a room at 60 degrees, on the supposition, that in consequence of the body being chiefly covered, the moisture given off does not at the utmost exceed 18 grains, it will be necessary to change 3 cubic feet of air per minute for each individual in the room.*

60. The air of a close room is also deteriorated by various other causes; the effect of candles, lamps, and other lights, it is of most importance to consider. It appears, that the quantity of oxygen consumed by a single candle, must render from 180 to 300 cubic inches of atmospheric air unfit for respiration; and we cannot allow less than one-fourth of a cubic foot of air for each individual, for these causes of impurity. And, it may be remarked, that warmth increases the exhalation of every species of noxious matter; hence, where a higher temperature than ordinary is necessary, a greater proportion of ventilation becomes essential.

61. A review of the various causes which we have shewn must necessarily vitiate the atmosphere in a

* In crowded places, the vapour exhaled frequently condenses on the walls, &c.; and in a late work on the "Construction and Ventilation of Meeting Houses," it has been traced to the true source, and assigned as one of the chief reasons for giving ventilation, p. 14.

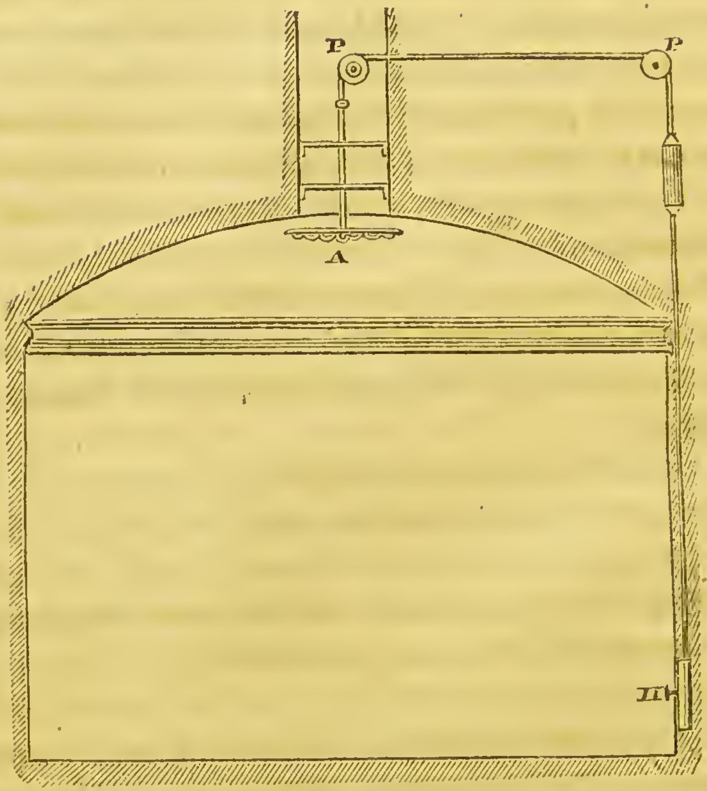
dwelling room, will render it clear that ventilation is indispensable, if health and cleanliness be at all desirable. Our next object must be to consider the manner of producing this ventilation, the quantity necessary, and the proper outlets for the vitiated air; and the place where fresh air should be admitted.

The quantity, of course, will depend on the number of individuals; and for each individual we should have (by art. 56) 800 cubic inches per minute,

(by art. 59) 3 cubic feet = 5184
(by art. 60) $\frac{1}{4}$ cubic foot = 432

Total, for each person, 6416 cubic inches; or very nearly 4 cubic feet per minute.

62. All this quantity will be of an increased temperature in regard to the surrounding air, and the heavy gas (carbonic acid gas) will be so mixed with azotic gas and vapour, both of which are lighter than air, that the combination must ascend, and occupy the upper part of the room; and will cool and mix with the air of the room, if not allowed to escape while its increased temperature gives it the proper degree of levity. Hence, the ceiling of an apartment is the proper place for the outlet: and the form of the ceiling may be such as will facilitate the ascent of the vitiated air to the outlet, as will appear by the annexed figure. When ceilings are domed, coved, arched, or groined, and the ventilating tubes ascend from the most elevated



parts, they are most favourable for ventilation; both as far as regards dispelling that part of the air which is most vitiated, and giving a higher column of rarefied air to cause its aseent. But there should be the means of opening and closing the aperture, so as to regulate the quantity of ventilation at pleasure. This may be easily effeeted by balaneing the plate A, which eloses the aperture by weights. The motion may be communieated by a line or a wire, over the pulleys P, P. All that is necessary to be attended to in the arrangement is to plaee either a part or the whole of the balance weight at H, the

part of the wire which is taken hold by to move it.*

63. The power of ventilation in a room should obviously be adapted to the greatest number of people it is supposed to contain at one time; and it is obvious that we had better err in excess than defect. Perhaps, however, a few examples, in round numbers, will afford my readers a more distinct idea of the quantity of air it is desirable to exchange in a minute in a crowded room. We have found (art. 61.) that there should be four feet per minute for each individual: therefore, when a room contains 200 people, there should be 800 cubic feet of air changed every minute; or a little more than would fill a room nine feet square and nine feet high. For 400 people, there should be 1600 cubic feet of fresh air every minute, to preserve the air from becoming vitiated; and so on in proportion. When we consider the actual ventilation of crowded rooms, it will not appear wonderful that they feel oppressive and disagreeable. And in estimating these quantities, if we have not been very strict in taking the lowest results, neither can we be assured that any ventilators will be of that perfect construction which would be necessary for the noxious part alone to be removed; and, therefore, the balance of purity will be barely sustained.

* This method appears to be nearly the same as the Romans employed to regulate the temperature of the Laconicum, or sweating stove. See Vitruvius, lib. V. cap. x.

64. The most difficult season for ventilation is the summer; and we may consider that there should not, in warm weather, be a difference of temperature exceeding 10 degrees; and with this limit as to variation of temperature, we shall have this rule for the area of the tubes.

Rule.—Multiply the number of people the room is to contain by 4, and divide this product by 43 times the square root of the height of the tubes in feet, and the quotient is the area of the ventilator tube or tubes in feet.*

* The area of the tube that would be sufficient to take away the vitiated air may be thus determined. Let h be the height from the floor of the room to the top of the tube in feet, a the area of the section of the tube in feet, $t-x$ the difference between the temperature of the air of the room and that of the external air, and B the quantity of air in cubic feet which is to escape through the tube in one minute.

Now, the force producing motion in this case, is the difference between the weight of a column of external and one of internal air, when the bases and heights are the same, which will be $h\left(\frac{t-x}{450+t}\right)$

And, by the principles of hydrodynamics—

$$60\,a\sqrt{\frac{64\frac{1}{3}\,h\,(t-x)}{450+t}} = \mathrm{B}.$$

But this supposes the aperture to be so formed that there is not a contraction in the stream of air; and it is found by experiment, that, in all cases this contraction diminishes the quantity discharged about three-eighths of the whole; consequently, we shall have, neglecting the fractions—

$$\frac{\mathrm{B}}{300} \times \sqrt{\frac{450+t}{h\,(t-x)}} = a.$$

That is, B cubic feet of air will be discharged per minute, through a tube of which the area of the section is a feet.

By the height of the tubes is to be understood, the height from the floor of the room to the place where the air escapes to the external atmosphere; and they must all be of the same height when there are more than one.

The space for admitting fresh air should be near to the floor, or in the floor of the room, and will be required nearly of the same size; for the difference in the bulk of air is only 1-48th part less when ten degrees colder; but it is better to make them at least double the size, in order to avoid a rapid influx of cold air.

In a room ventilated in this manner, an open fire is inadmissible; but in the chapter on grates (Chapter X.) we shall have occasion to consider how the two plans may be combined.

65. *Loss of Heat.*—There will be, for each individual, 4 cubic feet of air per minute, conveying off a quantity of heat equal to the difference between the heat of the external air and that of the room. There will also be a considerable loss from opening and shutting of doors, without improving the venti-

When the difference of temperature between the internal and external air is five degrees, $\frac{B}{30\sqrt{h}} = a$; when ten degrees, we have $\frac{B}{43\sqrt{h}} = a$, which is the rule in the text. And, when the difference of temperature is 30 degrees, which will often be the case, we must have the power of reducing the aperture to $\frac{B}{75\sqrt{h}} = a$; and when the difference is 56°, $\frac{B}{100\sqrt{h}} = a$: and so of any other difference of temperature.

lation; but the heat of the room will not be so altered by these partial changes, as to render it necessary to allow for them.* The crevices round windows and doors allow a considerable quantity of air to enter and to escape, without improving the ventilation; for the quality of the air is not improved by allow-

* If a doorway be constantly open, and h be its height, and we consider that point in the height where the air is not in motion to be at half the height, then b being the breadth, the area of the space through which air enters will be $\frac{1}{2} h b$; and substituting this value of a in the equation $\frac{B}{300} \times \sqrt{\frac{450+t}{h(t-x)}} = a$, we have

$$B = 150\, b\, h^{\frac{3}{2}} \sqrt{\frac{t-x}{450+t}}.$$

This supposes the velocity to be the same at all points in the height, but it will vary so as to be zero at or near the middle; therefore, according to the principles of variable quantities, the above expression should be divided by the index of the height, which gives

$$B = 100\, b\, h^{\frac{3}{2}} \sqrt{\frac{t-x}{450+t}};$$

where B is the quantity of air flowing in per minute in cubic feet; if $t-x=60°$, we have

$$B = 34\, b\, h^{\frac{3}{2}}.$$

The influx of air at crevices and joints at the sides of doors and windows may be easily estimated by this equation; where b must be the sum of the horizontal breadths of the joints in feet. The breadth of opening of the joints of a well-fitted door should be 1-200th of a foot; but they more frequently measure twice that quantity, and in that case $B = \cdot 34\, h^{\frac{3}{2}}$. And we see that high doors will tend more to cool rooms than in proportion to their increase of height. The average height is about seven feet; and taking it at eight feet, to allow for the bottom and top, the quantity flowing in when the difference of temperature is 60°, will be $11\frac{1}{4}$ cubic feet; and the same quantity may be allowed for windows.

ing any to escape at any place much below the level of the ceiling; and it appears from a preceding note, that in the extreme season, for which the quantity of heat should be estimated, it will, at an average, be 11 feet per minute for each door and window communicating with the external air; internal doors admit air, but the air so admitted being warmer, and in general no more than equivalent to that required for supplying the ventilation at the ceiling, they need not be considered.

66. The solid matter of the walls, floors, and ceilings of an apartment, after being raised to the temperature of the air, take away only a very small portion of heat when formed, as usual, of wood, plastering, or other slow conductors. But the glass of the windows suffers heat to pass through in considerable quantity; we must therefore consider the cooling effect of the external air on glass.

To determine the quantity of heat transmitted through glass in each minute, we shall find it an advantage to measure it by the quantity of air cooled down from the temperature of the room to that of the external air. The principles stated in Chapter III. art. 37 to 42, apply to this purpose; and from these principles it may be shewn, that the quantity of air cooled in a given time, is simply proportional to the surface of the glass exposed to the external air: and, consequently, will be constant, whatever variation of temperature may take place. This result is a consequence of measuring the quantity of heat that escapes by the quantity

of air heated to the same number of degrees, as the excess of temperature of the surface giving off heat.*

67. Rule.—If the area of surface of glass be multiplied by 1·5, the product will be the number of cubic feet of air per minute which will be cooled from the temperature of the room to that of the external air.

From these estimates of the cooling circumstances, it is easy to form a general rule of sufficient accuracy for practice, with such limitations as it will be proper to introduce.

68. Rule.—In public buildings, dwelling-houses, &c. the quantity of air in cubic feet to be warmed in one minute should be equivalent to four times the number of people the room is intended to contain, added to eleven times the number of external win-

* It is shewn (in a note to art. 42) that $0{\cdot}000644\ (T-t)\,s=\varepsilon$, when the surface giving off heat is glass. But the heat of the surface of the glass will generally be less than the mean temperature of the room; and in the extreme case of cold, this difference may be taken at $\frac{1}{6}$; therefore, when $\varepsilon = T - t$, we have

$$\frac{5 \times 0{\cdot}000644\,s}{6} = 1. \text{ or } s = 1853.$$

Now, as this quantity of surface will cool down 2850 cubic feet of air, from the temperature of the room to that of the external air, we have

$$1853 : 2850 :: 1 : 1{\cdot}5 \text{ nearly.}$$

That is, one foot of surface of glass will cool $1\frac{1}{2}$ cubic feet of air, from the mean temperature of the room to that of the external air in each minute, which is the rule in the text.

dows and doors, added to one and a half times the area in feet of the glass exposed to the external air: the sum will be the quantity in cubic feet, which is to be used in art. 44, in calculating the quantity of surface of steam-pipe, or in art. 55, in calculating the quantity of fuel.*

If the windows be double, and shut so close as to prevent motion in the air between the two windows, then the cooling from ventilation alone will have to be taken; that is, four times the number of people the room is intended to contain, will be equal to the cubic feet of air to be warmed in one minute.

If the windows be rendered simply air-tight, then the number of them multiplied by 11 may be neglected.

If the cubic feet of space in a room, be divided by the quantity of air to be warmed in one minute to sustain its temperature, the quotient will be nearly the number of minutes it will require to raise it to the given temperature; the ventilation being stopped during the time. But this will soon be found by trial; and where the windows are double it will be desirable to have extra pipe, on purpose to raise the heat to the proper degree in a shorter time. Indeed, this method will be found to save both time and heat in many instances.

* If P be the number of people the room is to contain, W the number of windows, and G the area of glass; then $4P + 11W + 1{\cdot}5G = A$. Hence (by art 44, note,) we have $\frac{t-t'(4P + 11W + 1{\cdot}5G)}{2{\cdot}1(200-t)} = s$, the surface of steam vessel in feet.

Of the Ventilation and Loss of Heat in Hot-houses, &c.

69. It perhaps may be very useful to have the power of varying the ventilation of a hot house in winter; but it cannot be right to make them perfectly air-tight, nor even to lessen the ventilation to an inconsiderable quantity; for a little attention to the effect of air on plants will be sufficient to prove that a small degree of ventilation is at all times necessary. The quantity of air which circulates through the apertures, between the glass of the roof, is amply sufficient for the purpose, when a roof is glazed in the closest and best manner; and a great deal too much in an ill-glazed roof, because it takes away such a quantity of heat. I prefer the little ventilation which is required in winter, being through the apertures between the glass of the roof, to any other mode of obtaining it; because, it is diffused so equably over the house, and no sensible currents can have place: indeed I consider the division of the admitted air into numerous small streams in this manner, to be the most favourable ventilation possible.*

* According to Scheele's experiments, the purity of atmospheric air is always diminished by germination and vegetation; Priestley's researches were attended with similar results; and Ellis has shewn that plants always consume oxygen, except when exposed to the direct action of the solar rays, (Murray's System of Chemistry, Vol. IV. pp. 20 and 37.) Also, it has been ascertained by Theodore de Saussure, (Journal of Science, Vol. XV. p. 317,) that more oxygen is necessary to develope flowers than leaves: in some cases above double the quantity is required, as in the pas-

70. *Loss of Heat.*—The influx and eflux of air through the apertures between the roof glass may be estimated with sufficient correctness to enable us to provide against its effect in the season of extreme cold. The mean vertical height of the sloping roof of a hot-house is about 10 feet, and when the difference of temperature between the air of the house and the external air is 30 degrees, an indifferently glazed roof will admit 5½ cubic feet of cold air in a minute, for each foot in length of the house.*

siflora serratifolia, and polyanthis tuberosa; hence, ventilation is most necessary in a flower-house, and, during the flowering season, in fruit-houses.

* From taking a mean of the apertures between the laps of the glass, in hot-houses, where no particular care had been taken in glazing, I found it to be about ·007 feet for each foot in height measured vertically. Hence, if the equation (art. 65, note) be multiplied by ·007, it will express the quantity of air in cubic feet that will enter in one minute, for this is only a particular case of the same problem, when the air flows through equidistant apertures. Hence,

$$\cdot 7\, b\, h^{\frac{3}{2}} \sqrt{\frac{t-x}{450+t}} = \mathrm{B}.$$

Where b is the length of the glass of the roof in feet, h its vertical height in feet, and B the quantity of air in cubic feet flowing in per minute. When $t-x=30^{\circ}$, and $h=10$ feet, then, $\mathrm{B}=b\times 5{\cdot}5$ cubic feet per minute, which is the case in the text.

If a roof be very well glazed, the apertures in a vertical foot do not average more than ·003 feet which gives 2¼ cubic feet per minute for each foot in length, and by mere closeness of glazing it cannot be reduced to less than this quantity, without resorting to either metal laps or putty.

It may be noticed, that when the vertical height of the roof is much less than the height of the house, this mode of computation

With the same height of roof, and the same difference of temperature, a well-glazed roof will admit about 2¼ cubic feet per minute for each foot in length.

But that we may not err in defect, for we have only taken a mean degree of variation of temperature, let us suppose that 5 cubic feet per minute enter in each foot in length, when the height of the roof does not greatly differ from 10 feet. And, as the escape of heat through glass has been already estimated, (art. 67,) as well as the air entering by crevices round doors, (art. 65,) we have the following practical rule for hot-houses.

RULE.--The heat given out by the fuel should be capable of raising, from the temperature of the external air to that of the house, as many cubic feet of air per minute, as 5 times the length of the glass of the roof in feet, added to 1½ times the whole area of glass in feet, added to 11 cubic feet for each door.*

Hence will be evident the importance of having no more glass than is favourably placed for affording light, and the advantage of a porch or double

is not strictly correct, but in general it will be sufficiently accurate for practice.

* Let D be the number of doors, G the area of glass, and L the length of the house, then, $5\,L + 1\frac{1}{2}\,G + 11\,D = A$. Hence, for steam-pipes (art 44, note) we have $\dfrac{\overline{t-t'}\,(5\,L + 1{\cdot}5\,G + 11\,D)}{2{\cdot}1\,(200 - t)}$ $= s$, the surface of steam-pipe in feet.

door for houses; and the latter will be a means of avoiding the immense loss of heat at every opening and shutting of the doors.

71. In stoves and forcing-houses, that are kept at a more elevated temperature, we must calculate upon a greater influx of cold air, and they are also more variable in height; and consequently, while we keep the same simplicity as much as possible in view, we must adopt a nearer approximation for the use of those who do not understand algebraic rules. The greatest difference between the temperature in a stove and that of the external air, will never exceed 50 degrees; and to provide the heat for this degree of cold, the following rule may be employed.*

Rule.—To the length of the stove in feet, multiplied by half the greatest vertical height in feet, add $1\frac{1}{2}$ times the whole area of glass, and also 11 times the number of doors, the sum will be the number of cubic feet of air to be heated in a minute, from the temperature of the external air to that of the stove; which, being used as directed in art. 44,

* In a note to art 70, we have $\cdot 7\, b\, h^{\frac{3}{2}} \sqrt{\frac{t-x}{450+t}} = B$; and when $t-x=50°$, we shall have nearly $\frac{b\, h^{\frac{3}{2}}}{4} = B$. And as a simple approximate rule for practice, we may make $\frac{b\, h}{2} = B$; when h is the whole vertical height of the house.

will shew the quantity of steam-pipe, or as in art. 53, will give the quantity of fuel.*

The application of these rules will be shewn in the chapter on stoves, &c. (Chapter IX.) and in houses greatly differing from the ordinary forms, recourse must be had to the algebraic formula in the notes.

Winds have a powerful effect in cooling the air of hot houses, and particularly in increasing the circulation of the air through the apertures and crevices; indeed, it always requires the greatest force of heat to sustain the temperature of a hot-house in cold and windy weather. But when the cold is very intense the wind is seldom powerful. Snow and rain also tend to cool the air of a hot-house very rapidly. These causes of loss of heat I have endeavoured to provide against, by taking a lower degree of cold for the external air than would otherwise have been necessary.

The effect of wind in cooling has been studied by Professor Leslie, to whom we are so much indebted for experimental inquiries respecting heat;† but till we have registers of the intensity of winds in con-

* If D be the number of doors, G the area of glass, L the length of the house in feet, and h the height in feet, we have $\frac{1}{4} L h^{\frac{3}{2}} + 1{\cdot}5\, G + 11\, D = A$, and for steam-pipes (art. 44, note)

$$\frac{\overline{t-t'}\,(\frac{1}{4} L h^{\frac{3}{2}} + 1{\cdot}5\, G + 11\, D)}{2{\cdot}1\,(200 - t)} = s,$$ the surface of steam-pipe in feet, which may be employed instead of the approximate rule in the text.

† Inquiry into the Nature of Heat. p. 278.

nexion with observations on temperature, it would be difficult to reduce those effects to regular rules.*

72. *Summer Ventilation of Hot-houses.*—It has now become common to fix the lights of hot-houses, and ventilate by apertures, for that purpose, according to the method employed by Dr. Anderson in 1801, for his patent hot-houses,† and afterwards applied to common hot-houses by Mr. Atkinson, in 1807; hence it is necessary to provide such a quantity of apertures as will keep the temperature of the house to a proper limit in the warmest day of summer.

In this climate, the action of the sun is often sufficient in summer, to raise the temperature of the air in a close hot-house to 120°, and the temperature of the air in the shade is sometimes 87°. Now, in such a case, if the temperature of the air of the house could be prevented from rising above 95° by ventilation, the plants would sustain no injury. This may be done by the following rule.

Rule.—Make the sum of the areas of all the upper ventilators, in feet, equal to the length of the rafter added to the height of the upright glass in front, if any, multiplied by the length of the house, both in

* Col. Beaufoy did attempt to give a register of this kind in Dr. Thomson's Annals, but did not continue it. There does not appear to be any difficulty in forming a wind-gage to register its changes; and it is to be hoped that this important but neglected branch of meteorology will be more carefully noticed, as it would not only elucidate the subject itself, but also be useful in many other inquiries.

† Repertory of Arts, Vol. XV. p. 303, old series.

feet; divided by six times the square root of the height, in feet, from the floor of the house to the aperture from which the heated air escapes.*

The openings for admitting cool air should be of the same size, for the expansion of the air by a change of 8° of temperature is only about 1-60th part of its bulk.

Examples of the application of these rules will be

* We have found, that when T is the temperature of the source of heat, $0{\cdot}000644\, s\,(T-t) = \epsilon$; (by art. 42, note,) and in the case now to be considered, $T=120°$, $t=95°$, and $\epsilon=95-87=8°$, hence,

$$s=\frac{8}{{\cdot}000644\times 25}=497.$$

Consequently, 497 feet of surface of glass, when exposed to the direct rays of the sun, would heat 2850 cubic feet of air per minute, or each superficial foot would heat $5\frac{3}{4}$ cubic feet of air per minute. Let LR be the area of the surface the sun acts upon, then $5{\cdot}75\,LR = B$. And this value of B being inserted in the equat. art. 64, note, making $t-x=8°$, we have $\frac{B}{300}\times\sqrt{\frac{450+t}{h(t-x)}}=\frac{{\cdot}15\,LR}{\sqrt{h}}=a$ or $\frac{LR}{6\sqrt{h}}=a$ nearly. Where L is the length of the house in feet, R the length of the rafter added to the height of the front glass, if there be any, in feet; h the height from the floor of the house to the place where the heated air escapes in feet; and a the area of the ventilating apertures in feet. The preceding calculation is not made from the greatest heat that has been observed in England, for, on the 13th of July, 1808, the thermometer rose in the shade to 92°, and in the sun to 126°. (Phil. Mag. Vol. XXXV. p. 425.) And in June, 1824, the temperature of air confined by glass and exposed to the action of the sun, I observed to be 130°, when the air in the shade was only 75°. Some interesting experiments on the force of solar heat are recorded in Mr. Daniell's Meteorological Essays, p. 207—249.

found in the chapter on hot-houses, &c. (Chapter IX.) where the construction of the ventilators will be shewn.

Of the Ventilation of Hospitals, Infirmaries, &c.

73. Buildings for the reception of people in a state of disease, require more than ordinary care to keep them pure and wholesome; because disease brings so many additional circumstances, all tending to vitiate the atmosphere. The breath is charged with fœtid effluvia, the perspiration is more abundant and more contaminating; a greater number of persons are crowded together, and are kept in the same place both night and day; the effluvia from their beds, besides various causes of impurity from particular diseases, all tend to deteriorate the air; while, if in any place pure air be essential, it surely must be in that which is appropriated especially to the restoration of health. Hence we should make the change of air more rapid than in dwelling-rooms; perhaps six cubic feet per minute for each individual will be sufficient.

In warm weather, all the circumstances tending to vitiate the air, act in an increased proportion; hence, the free ventilation of an hospital is still more necessary in summer than in winter. Let us, therefore, endeavour to direct the little knowledge we have obtained of the subject, to improve these excellent institutions; let us try to make them as far as possible fulfil the intentions of their benevolent supporters, for we cannot direct science to a more desirable object than to alleviate the sufferings of our fellow creatures.

74. From the nature of all airs to mix, when suffered to be long in contact,* we ought to endeavour to remove any impure or noxious air as soon as it is produced, and therefore, the ventilation should be continual. But the tendency of airs to mix is increased by agitation; hence, no means should be employed to agitate the air, except it be at particular times when the air is passed through in large quantities to purify the apartments.†

75. We have two means of producing continued

* See Thomson's Chemistry, Vol. III. p. 32, where the results of many experiments are collected.

† When the solid matters of the wards of an hospital have become saturated with fœtid effluvia, this mode of purification is not sufficient. The following extract from Dr. Thomson's Chemistry gives a brief but comprehensive view of the means that may be successfully employed in aid of ventilation. "Vinegar diminishes the odour, but its action is slow and incomplete.—Acetic acid acts instantly and destroys the fœtid odour of infected air completely.—The fumes of nitric acid, first employed by Dr. Carmichael Smith, are equally efficacious.—Muriatic acid gas, first pointed out as a proper agent by Morveau, is equally effectual.—But the most powerful agent is chlorine gas, first proposed by Mr. Cruikshanks, and now employed with the greatest success in the British navy and military hospitals."—"The last deserves the preference, because it acts with greater energy and rapidity. All that is necessary is to mix together two parts of common salt, with one part of black oxide of manganese, to place the mixture in an open vessel in the infected chamber, and to pour upon it two parts of sulphuric acid. The fumes of chlorine are immediately exhaled, fill the chamber, and destroy the contagion. Or the oxymuriate of lime, sold for the purposes of the bleacher, may be mixed with sulphuric acid, and placed in the infected apartment." (Vol. III. p. 194.) See also, Fourcroy's art. Méphitisme, Chimie, Encyc. Méthod.

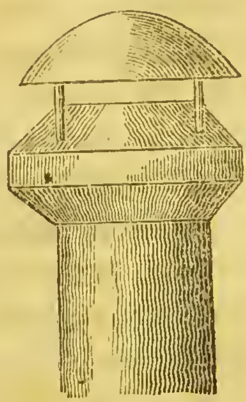
ventilation; the one by heat, and the other by mechanical power. In many cases both may be employed with advantage; and they will, in either case, produce the greatest effect when they act immediately, upon the most impure kinds of air in the apartment, (as stated in art. 62.)

In conformity with this principle, what is lighter than common air, such as azotic gas, vapour, and effluvia, should be drawn from the top of the room, and by means of ventilator tubes not very distant from one another. If the impure air be to escape in consequence of its own levity and elevated temperature, which in this case will be sufficient, it should be through tubes of uniform diameter, for every enlargement produces eddies and interrupts the discharge of the air. Each tube should be independent: for if currents be let into the same tube from different apertures, they will cross each other and interrupt the flow of air. The tubes of rooms on the same level, which communicate with one another, should be all taken to the same height, otherwise cold air will blow down some of them, and if this does not happen, the effect of the lower tubes will be less than that of the others.*

But several tubes from the same level may be opened into one common top with advantage, and this top, whether for single or other tubes, should

* An open fire with a chimney in a ward is inadmissible with this mode of ventilation, and will completely stop it; for a current of cold air will either come down the ventilating tube, or the room will smoke.

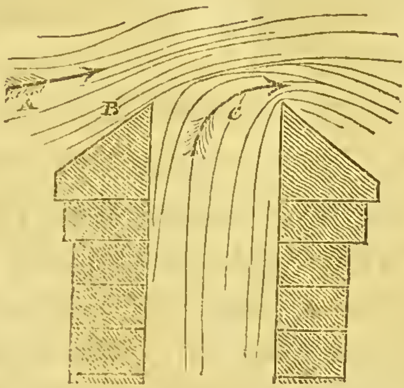
be either moveable, with a vane to turn its aperture from the wind; or, because these moveable tops or cowls, when not very accurately made and kept in good order, produce a disagreeable rattling and creaking noise,* and to make them well renders them expensive, we may often employ with advantage a top formed in the manner described in the figure.



The tops may be of thin metal painted a dark colour, and exposed to the free action of the sun's rays. The upper cap prevents down blasts of air, but in a steady horizontal wind the lower cone alone would be sufficient. Its action is easily understood by a reference to the next figure; for when a current of wind, moving in the direction AB, impinges on an oblique surface B, it is deflected, and rises over the aperture C, leaving a space for the air to rise

* When a cowl runs in leathern collars, it makes much less noise.

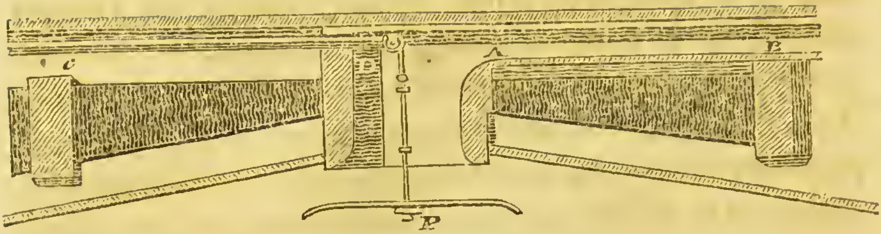
and mix with the wind: it will even draw the air out of the flue instead of interrupting it.*



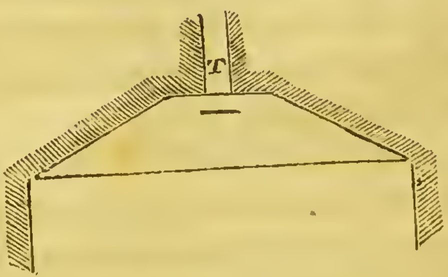
The area of the tubes should never be greater than is wanted for the extreme quantity of ventilation; for a tube that is larger than necessary, will either allow a double current, or the rising current will be retarded by eddies.

The best form for the mouth of the tube with its register, will be a circular aperture, as shewn in the next figure, (p. 94.) with a balanced circular plate P to close it. The plate should be larger than the aperture, in order that the air may be drawn into a horizontal current, for the purpose of taking away the portion of the air next the ceiling. If the tube were left without a plate, the air immediately under it would press forwards up the tube, and very little of the worst air which collects at the ceiling would escape.

* These tops are described in the Journal de Physique, for 1788, p 161.



76. A flat or level ceiling is very ill adapted for ventilation. They ought always to be dome-shaped, or of the form of a truncated pyramid, as shewn in the annexed figure, so as to rise in the centre, and at this centre the ventilator tube T should be placed.



When we do not attempt to employ curved lines, ceilings of this kind are not much more expensive than flat ones: they look better, and are admirably calculated for the important object of good ventilation.

We cannot always proceed in a vertical direction from the centre of the ceiling; but there is no great objection to the first part of the tube being nearly horizontal, where we can have a considerable height of vertical tube when we arrive at it;

and it is fortunate, that, usually when we cannot ascend in a vertical direction at first, we almost always can have a sufficient height of vertical tube. The last figure to art. 75, shews how the horizontal part of the air tube will pass between the timbers of a floor; AB is the air tube, which should be got as deep as possible, so as not to cut the timbers. The same figure will shew how the timbers of a floor may be disposed, so that there may be a rise in the centre without loss of space. A flat curve would greatly improve the appearance. C is a cord, which is passed over a pulley D for raising or lowering the plate, P, as described in art. 62.

77. In the next place, we have to consider how a supply of fresh air should be obtained; for if fresh air be not supplied, there will be a risk of a double current in the ventilating tubes.

Fresh air in summer should be obtained, if possible, from the shaded side of the building, as, by that means we shall have an effect equivalent to the thorough air which Galen thought to be so very necessary. To effect the admission of cold air in the best manner, there should be many openings over a great extent of space, and the openings again divided into small spaces by the kind of wire work called wire gauze, so that the air may have no sensible current.*

* The good effect of thus dividing the current of air into small streams, I found had been noticed before I tried it, by Clavelin, who appears to have found it equally beneficial. (See Caminologie, Dict. de Physique, Encyc. Méth.) and Mr. Gilbert has re-

When the windows happen to be at the shaded sides, the ventilation will be easily effected, by letting in the air at the lower part of them: by no means opening the top. When the windows do not happen to be on the shady side, we may obtain the cool air from that side by air tubes, which may be rendered farther useful in the arrangement for warming in winter, as will be afterwards shewn. But in whatever manner fresh air is obtained, it should be introduced near to the floor, and at various places, and dispersed as much as possible to avoid currents. The place of admission must be near to the floor, or at gratings in it; but not nearer to the ceiling than can be possibly avoided.

To reduce the velocity, the area for supplying fresh air must always be greater where it enters the apartment, than that for the escape of impure air; but where it is admitted by tubes, the mouth of the tube, or entrance from the external air, may be with advantage made equal to or rather smaller than the tube for the escape of impure air.

78. Having provided for admitting a fresh supply of air, we may proceed to consider how the heavy impurities are to be discharged, which may accidentally collect in the passages. If any opening were made to the external air, cold air would enter with difficulty, and have no tendency to free us of the

marked that "one obvious expedient is to subdivide the current into numerous streams." Quarterly Journal of Science, Vol. XIII. p. 116.

heavy airs, already at a balance with the atmosphere by their greater specific weight. But they must not be suffered to collect in the passages, otherwise a greater evil is created than we seek to remove; for nothing can be more objectionable than diffusing impure air through the passages.

Now, if we provide a full supply of fresh air, a small power would be sufficient to abstract the air rendered heavy by the carbonic acid gas, which is accidentally diffused in consequence of being condensed before it arrives at the ventilating tubes; therefore, it appears to me that it would be most certainly effected by means of a ventilator similar to that invented by Dr. Hales, or the still more simple one of Mr. John Taylor,* worked by a

* See Transactions of the Society of Arts, &c. Vol. XXVIII. p. 218, or Repertory of Arts, Vol. XVIII. p. 377. When the parts are balanced, the resistance of Taylor's machine is easily calculated. Let B be the quantity of air to be exhausted per minute, and a the area of the pipes, then $\frac{B}{60\,a}$ = the velocity in feet per second, and $\sqrt{64\,h} = \frac{B}{60\,a}$, by the principles of hydrodynamics; where h is the height of the column of air in feet, the weight of which would produce the velocity, and we have $h = \frac{B^2}{230400\,a^2}$, therefore, the weight of the column, or $h\,a \times \cdot 0753 = \frac{B^2}{174791\,a}$. In practice, we shall lose about half the effect of the power in the friction of the machine, the friction of the air, and the power expended in opening the valves. Whence, $\frac{B^2}{87000\,a}$ pounds, with a velocity $\frac{B}{60\,a}$ feet per second will be required, or a

regulated power on the principle of clock work, and with the addition of an apparatus for opening the valves. The expense of labour to raise a weight every day to keep it in constant action, would be much less than the expense of fuel and attention to produce the same effect by fire, besides the action being more certain.

To produce the effect we desire, the best plan

mechanical power of $\frac{B^3}{5,220,000\,a^2}$ pounds one foot per second, or more conveniently $B\left(\frac{B}{2285\,a}\right)^2$ = the mechanical power. The force of a man, such as would be likely to be set to work of this kind, would not exceed 20lbs. raised one foot per second, therefore $\frac{B}{20}\left(\frac{B}{2285\,a}\right)^2$ = the number of men to pump B cubic feet of air per minute. It is obvious that the larger we make a, the area of the pipe, the less power will be necessary. When we make $a = 1$ square foot, and $B = 470$ cubic feet per minute, $\frac{B}{20}\left(\frac{B}{2285\,a}\right)^2 = \frac{470}{20}\left(\frac{470}{2285 \times 1}\right)^2 = 1$ nearly: whence, one man of the power we have considered, will change 470 cubic feet of air per minute. The ratio of the velocity through the pipe to the velocity of the cylinder, should be as the diameter of the cylinder is to the diameter of the pipe; if the ratio be made different there will be a loss of effect.

This contrivance, when executed in a proper manner, and proportioned on true principles, may be effectively applied in aid of the ventilation of mines, and particularly coal mines. A steam engine of 11 horses' power would change all the air in the workings of a coalery of a mile square once a day, supposing the seam to be five feet thick, and the whole cleared of coal as far as practicable; and with the advantage of directing the action to any particular part of the pit, there would be very little risk of an accumulation of fire-damp.

seems to be to have open gratings in various parts of the passages, with tubes from each to the place of the ventilator; and the gratings might be provided with slides, so that the action might be confined more to particular parts as occasion might require.

79. There is another important part of the ventilation of hospitals, &c. to be noticed, which is the water-closets. We cannot prudently mix this process with the other ventilation, but it may be easily effected when these conveniences are situate any way near to a place where it is necessary to have a boiler for hot-water.

Thus, let the boiler have a cover of sufficient weight to confine the steam, and let a pipe, on the principle of a distiller's worm, pass from the top of the boiler up the middle of a trunk or air tube, through the closets, and return to the boiler by a smaller pipe, furnished with a cock to let out the air when the apparatus is set to work. The steam which rises and condenses in the steam-pipe, will afford a continual supply of heat to air in the trunk, which being made open at the top, with a vane to turn its mouth from the wind, and being supplied only from the closets, its effect will be to draw a continual current of air from them, while they are supplied with other air from the passages of the house.

Another method may be employed, in this manner. Let a flue be formed of sufficient magnitude to contain a copper tube within, which copper tube should form the smoke-flue of a fire that is con-

stantly kept on. The warmth which a pipe of this kind would communicate to the air in the flue round it, would cause an ascending current of air, which, being supplied from the closets, they would be constantly ventilated without trouble or attention. If the copper pipe formed the smoke flue to a close or boiler fire-place, it would be still more effective.

The usual means resorted to for ventilating hospitals are not adapted for the purpose; because they can act only on the condition, that the air in the hospital is specifically lighter than the external air.

Having now considered the most useful particulars regarding ventilation, and the causes of loss of heat, I shall proceed to describe the construction of apparatus, and their principles of action, and then give examples of their application, and the proportions for practice.

CHAPTER V.

OF BOILERS, THE CONSTRUCTION OF BOILER FIRE-PLACES, AND THE APPARATUS OF BOILERS.

"In the best fire-places the increase of effect does not depend merely on the rapid current of air, but likewise upon the heat preserved by the arrangement of the materials of the chimney, and communicated to the matters entering into inflammation."

SIR H. DAVY'S RESEARCHES ON FLAME.

81. IN order to make this part of my subject as clear as I can, and to give it that full investigation its great utility renders necessary, it will be convenient to treat first of Boilers, secondly of Fire-places, and thirdly of Apparatus.

Of Boilers.

82. In treating of boilers, we have to consider the form and materials for producing steam with the least expenditure of fuel, and with the least attention: incidentally shewing the best forms and proportions for other purposes, such as evaporating liquids; chiefly because the two kinds have been supposed to require the same proportions, or, that what is proper for one has been supposed proper for the other. And in treating of these subjects our chief guides must be simplicity, durability, and safety.

The matter of which the part of a boiler is made which is to receive the immediate effect of the fire, should obviously be a good conductor of heat.* Copper is a better conductor than iron, but both these metals conduct well. The metal should not be polished; in fact, an open grained and blackened surface next the water will be found an advantage. But for those parts of a boiler which have not to transmit heat from the fire, slow conductors of heat may be employed with benefit.

Boilers for generating steam are made of various forms; the most common are those called waggon boilers, from their resemblance to the form of a tilted waggon; they are rectangular, with a semi-cylindric top, and the bottom usually curved, with the concave side next the fire; sometimes the sides are also curved. Others employ circular boilers with a semi-globular top, and these also are sometimes made with concave bottoms.

83. The bottom of a boiler should be thin, because it will transmit heat better;† for even the best conductors retard the progress of heat when they

* The advantage of a good conductor may be seen by boiling water in a glass vessel; the operation goes on by starts and with difficulty; but strew in a few iron filings over the bottom, and the water will boil freely. Glass is a slow conductor.

† Count Rumford made known the curious fact of a thin boiler being the best, (Essay X. Sect. II.); and the effect of thickness is illustrated by Professor Leslie's experiments, who exhibits a mode of calculating the reduction of effect which an increase of thickness occasions, (Inquiry into the Nature of Heat, p. 511.) Mr. Fourier has also considered this problem, (See Quarterly Journal of Science, Vol. XIII. p. 145.)

are of considerable thickness. To make it thin will save time in raising the water to the boiling point; and it will also be more durable, because the surface next the fire will require a less intense heat. A thick boiler has scarcely any effect in regulating the action of the fire.

The bottom should have a sufficient extent of surface to receive all the force of the fire, as far as the heat of it is capable of being extended so as not to be less than 212 degrees; a greater surface cannot generate steam; a less will not produce the greatest effect. And it is clearly a disadvantage to suffer the smoke of the fire to come in contact with the boiler after its heat is less than that of boiling water; for if it be continued in contact with the boiler, it will rob it of heat instead of adding to the effect of the fire. When a boiler is used for high pressure steam, the smoke must quit the boiler at the temperature of the steam.

84. If it be considered an object to save the heat which is taken off by the smoke escaping at 212°, it should be made to warm the water intended to supply the boiler; by this means a considerable saving might be made;* and the steam boiler, being

* The idea of supplying a boiler with warm water is very ancient: for a method of doing it has been described by Vitruvius, and in such a manner as to leave no question of his knowledge of its advantages; but he has so obscurely described the method as to furnish ample scope for the kind of speculation commentators love to indulge in. (See Perrault's Vitruvius, liv. V. chap. x.) Perhaps Count Rumford carried this mode of saving fuel to the greatest extent in practice. (See Essay X.)

fed by warm water, the steam would be generated more uniformly. In order to warm the water in the supply cistern, the smoke might pass through the cistern in iron pipes; and this will be found one of the most effectual methods of reducing the quantity of noxious smoke. These iron pipes would require frequent cleaning, and the draught would be considerably checked, particularly in a low chimney.

85. The depth of water in the boiler need not be greater than is necessary to prevent a risk of accident from want of attention to the fire; but, where the heat is to be kept up during a considerable time, as in hot-houses, it will be best to have a deep boiler, to retain a greater body of heat; and in this case every precaution should be used to prevent heat escaping from the boiler. A considerable body of water is also an advantage in a steam engine boiler, to prevent oscillations in its power to fill the cylinder with steam. Otherwise, a deep boiler requires too much time to make the water boil; which is particularly objectionable in warming manufactories, rooms, &c. and there will be a greater loss of heat continually taking place at the boiler; also the water requires a somewhat higher temperature to cause ebullition. Steam boilers usually have half their capacity filled with water, and this proportion appears to be a good one.

86. In regard to the space for steam in a boiler, there should always be sufficient to fill all the steam-pipes that are to be in action at one time; a less re-

serve of steam will cause some delay in getting the pipes into full action; and it is not very desirable that a greater reserve should be kept, on account of the heat lost at the boiler, unless the heat that escapes at the boiler be employed for some useful purpose. Two smaller boilers will always be found preferable to one large one; and let them be placed close together, in order to have a less mass of matter to absorb heat, and less surface for heat to escape. Two boilers are necessary to prevent risk from accidents, and to allow an opportunity for repairs. According to Hassenfratz, a boiler to contain about 11 cubic feet of water, is the most economical size, and the depth one-sixteenth of the area; that is, if the area be 16 feet, the depth should be one foot;* but these proportions only apply to boilers for evaporating liquids. For producing steam, the most effect is obtained when the horizontal area of the boiler is about 21 superficial feet. When a boiler is for evaporating, a great surface should be exposed to the air; but in a boiler for generating steam there is no advantage in giving a large upper surface of fluid, as has been remarked by the late Mr. Watt.†

87. The spherical form seems to be the best for a boiler; but unless it be cast in iron, it is not so easily made as some other forms; it combines the advantage of affording the most space with the least

* Encyc. Méthod. Physique, art. Claudière. The advantage of exposing a large surface to the air in evaporating, shews the effect of the air's affinity to vapour.

† Robison's Mechanical Philos. Vol. II. p. 108, note.

quantity of surface, it is a good form for the fire to play against; and nearly the strongest form that can be employed.*

A cylinder is the next in simplicity of form, and has partly the advantages of a spherical one; the waggon-formed boiler is an extremely weak form, when the bottom is flat, and weaker still when the bottom is convex towards the inside of the boiler, unless it have abutments as an arch. The same remark applies to convex sides. When the sides and bottom are made concave to the inside, it approaches in form to the cylinder, and is stronger in proportion as it is nearer to the cylindric shape. Boilers of a cylindrical, or waggon form, with flat ends, are in general proportioned so that the width being 10 parts, the depth is 11 parts, and the length 25 parts.

88. The apparatus for a boiler should be simple. There should be a contrivance to feed it with water, a safety-valve, a man-hole to clean it out at, and a cock to let off the water when it is to be cleaned out. These we shall consider after having treated of the fire-place, and the *description of the plates* will convey some further information respecting them.

* To form an idea of the best shape for a boiler, conceive the form it would assume if made of flexible materials and filled with steam and water. If it were filled with steam alone, a sphere would be the best form; the weight of water at the bottom would alter the form a little, supposing it to be suspended at the middle of its height. On this subject, Emerson has written something which seems to have escaped the attention of the designers of steam boilers. Prop. XCV. Mechanics, 4to. edition.

Of Fire-Places.

89. In the construction of fire-places for boilers, we have to combine every thing which is likely to add to the effect of the fuel, and to avoid every thing which tends to diminish it, as far as possible. Now, without some knowledge of the nature of the operation of burning, it will scarcely be possible to do any thing good except by mere accident; we should be like seamen in a vessel at sea without a compass, with as little chance of steering to the intended port.

90. When a portion of fuel is set on fire in a *close fire-place*, it must be supplied with a stream of air, otherwise it will not burn. Also, the fuel itself, in the process of burning, is partly converted into gaseous matter, which escapes up the chimney with a portion of the air supplied to the fire. But the greater part of the air supplying the fire ought to be changed in the process, by its oxygen uniting with the carbon and other combustible parts of the fuel, forming carbonic acid gas, vapour, &c.

Now, in order that perfect combustion, or burning of the fuel, may take place,* the air should have free access to every part of the fuel, which is heated sufficiently to burn; as fuel must be heated in a

* Perfect combustion of the fuel is to be understood only as far as it is consistent with obtaining the greatest degree of useful effect. It must never be pushed to that point when the gaseous products, and the air necessary to blow the fire, consume more heat than the fuel generates.

certain degree, otherwise its elements will not combine with the oxygen of the air. And we see clearly the advantage of a regular supply of fuel. This advantage is greater in proportion to the quantity of hydrogen contained in the fuel: for, if a large body of such fuel be put at once on a fire, much of the hydrogen will escape in a gaseous state unconsumed, carrying off with it a very considerable quantity of heat; whereas, if the fuel be thinly scattered over the surface of the fore part of the fire, the hydrogen would most likely be consumed in passing over the red-hot embers in the after part of the fire, and the product go off in steam. And that the latent heat of such steam may not be lost, it will be desirable to have a horizontal flue of metal for the smoke to pass along, after it has left the boiler, when the steam can be condensed and the heat applied to warm water for the boiler, or other useful purposes.

But to succeed in consuming the combustible gases, it is necessary that they should mix with air that has become hot by passing "through, over, or among fuel which has ceased to smoke,"* or by being drawn through small flues or channels in the brickwork round the fire,† in such a manner as to be

* I here use the words of the patent of Mr. Watt, dated 1785. See Repertory of Arts, Vol. IV. p. 227. old series.

† A method of producing this effect is described in a paper, "On the Construction of Fire-places for Steam-Boilers," by J. and P. Taylor. (Dr. Thomson's Annals of Philos. Vol. XII. p. 51.) It consists in making air channels behind the fire-bricks which line the fire-place, with small apertures opening into the fire-place at

heated before it mixes with the gas to be consumed. A reference to art. 26 will inform the reader to what species of coal this introduction of fresh air will be useful; for unless it happens that hydrogen or some of its combinations are constantly passing off, the introduction of a stream of air into the fire-place will only take away heat from the boiler. And, therefore, in a slow fire it will do more harm than good; while, in a quick fire of cherry coal or cannel coal, it must be a great advantage,* and particularly when the fire is regularly supplied with fuel, as it is by Brunton's apparatus.

91. The quality of the air to supply the fire is another thing worthy of being considered, although any dirty wet hole is usually esteemed good enough for the fire-place. Now, the air ought to be dry, for air charged with moisture is improper, and only takes away heat. But where there is a very low chimney, and consequently an imperfect draught, some water in the ash pit will increase the draught by being converted into steam by the heat of the

the sides, and just above the red-hot fuel. Whenever this method is adopted, a regulator would be useful to gradually close as the fuel ceases to flame.

* If cold atmospheric air be allowed to enter, so as to mix with the gases expelled from the fuel, it will reduce the temperature of these gases so much, that they will not inflame: for it has been clearly shewn by Sir H. Davy, that a temperature incapable of communicating visible ignition to metal is insufficient to keep up the combustion. (Researches on Flame, Phil. Mag. Vol. L. p. 5.)

ashes. The mixture of steam rendering the smoke much lighter than common air. The air should be cool when it enters the ash-pit, that it may pass with greater velocity through the fire; and the fire-place shed should be dry, in order that the apparatus may be durable, and keep in order with little attention.

The opening to admit air to the fire should be sufficiently large for producing the greatest quantity of steam that can be required, but not larger; and it should be constructed so as to increase in size as it approaches the fire. The area of the spaces between the bars, should clearly be, much greater than the area of the place that admits air to the fire; the area of these spaces, and that of the fire-place, will be found by art. 97.

92. The fire should be immediately under the boiler, so that its full effect may be exerted upon the bottom; and, after quitting the fire, the mixture of flame and smoke should pass through a wide and shallow aperture called the throat; wide, that it may spread under the greatest surface of boiler; and shallow, that it may pass through with considerable velocity, and consequently be impelled against the bottom of the boiler. The distance to which the flame and heated smoke of a fire will extend so as to be effectual, (see art. 83,) will depend on the draught of the chimney, and the nature of the fuel; from 3 to 6 feet will be about the range in a well constructed fire-place, for the use we are consider-

ing:* that is, about 6 feet with coals and a good draught, and about 3 feet with coke and a very slow draught. This, of course, will regulate the length of the bottom of the boiler; as to the usual mode of making the flue circulate round the sides of a long boiler, the heat never extends far enough to render it effectual throughout its length, and the action is oblique and less powerful than when exerted on the bottom. For like reasons, there is no advantage gained by returning the flue through the boiler, as you may as well confine the heat to act on the bottom, and have less depth of water, and a less complicated boiler. Count Rumford's plan of dividing the flame and heated air, in its passage to the chimney, is a good one.† To employ the heat which the smoke must necessarily retain when it leaves the boiler, it may (as has been before remarked) be made to pass through an iron pipe, the surface of which

* When the gaseous matter which heat expels from the fuel is burnt by introducing hot air amongst it, in the manner described in art. 90, a greater length of fire-flue will be effectual. This method of introducing air, has been re-invented several times, or rather, it has been attempted to do it in every possible manner. The first idea seems to have originated with Watt, in his patent in 1785. It was applied in a different manner by Thomson, in a furnace which could answer only in the hands of a most careful stoker. (Repert. IV. 316, 1796.) Roberton had a patent for the employment of the same principle, applied in a different manner; but certainly not so as to produce the best effect on the boiler, (Phil. Mag. Vol. XI.) : other patents have been obtained by Sheffield, Parkes, Wakefield, and Johnson, for applying the same principle. (See Technical Repository, Vol. I. pp. 16 and 42. London Journal of Arts, Vol. I. p. 403, &c.)

† Essay X. p. 44.

would either heat water or air: the latter method was adopted by Mr. Snodgrass.*

93. The next object to be considered is the nature of the chimney; for, in a close fire-place for producing steam we must have considerable draught, and this depends on the height of the chimney, the area of its section, and the temperature at which the smoke is allowed to enter it. The top of the chimney should not be larger than is required for the greatest quantity of fire.† If it be larger than necessary, the draught will be materially injured by it. The intermediate part of the chimney, between the top and the boiler, should be larger than it is at the top, and as free from abrupt changes as possible.

In order to know the quantity of area necessary for a given consumption of fuel, we must estimate from the analysis of the combustible, for it is not easy to make a direct experiment. Now, in caking coal, according to Dr. Thomson's experiments, (art. 26,) we shall have for the products of the perfect combustion of 100 grains of coal,

* Mr. Snodgrass surrounded the flue with a casing, through which a stream of air flowed, and conducted the heat given off by the flue into the work-rooms of the cotton-mill. (See Trans. Society of Arts, Vol. XXIV. p. 122. 1806.)

† When the chimney is properly contracted at the top, it is not much disadvantage for the other part of the flue to be larger, but it should be regular. When a chimney is not larger than is necessary at the top, it is less liable to have the smoke interrupted by winds, as has been shewn by Clavelin. (Encyc. Méthod. Physique, art. Caminologie.)

4·18 (1 hy. + 8 oxy.) = steam		38 grains,	or 200 cub. in.
75·28 (1 car. + 2·75 oxy.) = carb. acid		282 ——	or 610 ——
Axote of composition + to azote of air required for combustion.	= azotic gas	865 ——	or 2900 ——
Total gaseous products		1185 grs.	or 3710 cubic inches.

And as 100 grs. of coal : 7000 grs. : : 3710 : 259,700 cubic inches = 150 cubic feet for one lb. of coal. But it is practically impossible to render all the air which passes through the fire effective in combustion; and, in consequence of some comparisons with practice, I suppose not more than two-thirds is effective; hence, we must have 225 cubic feet for one lb. of caking coal. This product will be about one-thirtieth heavier than the same bulk of common air at the same temperature; and, therefore, 16 degrees must be deducted from the excess of heat in estimating the power of the chimney.

Coke and charcoal will give about 260 cubic feet for each lb. when estimated in the same manner; and about the same allowance is necessary for temperature.

For wood, 140 cubic feet for one lb. of fuel will be required, with no reduction of temperature. In burning wood, there will be great advantage in condensing the vapour by causing the smoke to pass along iron pipes.

The area of the ash-pit, or current of air to supply the fire, will be required about one-tenth less than that of the chimney for coal and coke, and about two-thirds less for wood.

94. It will be more convenient to estimate by the effect to be produced, than by the weight of fuel: and I shall consider the apertures necessary to convert a cubic foot of water into steam per hour; from whence those for any other quantity in the same time will be easily calculated.

For coals (by art. 23 and 93)	we have $225 \times 8{\cdot}4 = 1890$	cub. ft.
coke (by art. 31 and 93)	$260 \times 7{\cdot}7 = 2000$	———
wood (by art. 28 and 93)	$140 \times 30 = 4200$	———

By these numbers it appears, that we may calculate on 2000 cubic feet per hour, to convert one cubic foot of water into steam, whether coals or coke be used, and double that quantity for wood to produce the same effect: and on these data, the following practical rules are founded.

If the air ascends directly from the boiler, its temperature will be 212°, and estimating the external air at the mean temperature, or 52°, we have 212 — 52 for the excess of heat, or 160°; but when coals are employed, this excess must be reduced 16°, (art. 93,) therefore, $160 - 16 = 144° =$ the effective excess of temperature.

Rule to find the area of the chimney, when the excess of temperature is 144°.

Divide 45 by the square root of the height of the chimney in feet, and the quotient will be the area of the chimney in inches that would be sufficient for producing the steam of one cubic foot of water per hour.* The sum of the area of the spaces be-

* For if h be the height of the chimney in feet, from the fire to the top; B the number of cubic feet of air to be discharged per

tween the bars should be at least the same, and the area of the space to let in fresh air to the fuel one-third less; because it is not expanded by heat.

hour, when of the same temperature as the atmosphere; and a the area of the aperture in square inches. Then, it has been shewn (in art. 64, note) that $\frac{B}{60 \times 300} \times \sqrt{\frac{450 + t}{h(t-t')}} = \frac{a}{144}$; but the air will be expanded by heat to $\frac{B(450 + t)}{450 + t'}$ (See Table V. art. 220.) Hence $\frac{B(450 + t)}{60 \times 300 \times (450 + t')} \times \sqrt{\frac{450 + t}{h(t - t')}} = \frac{a}{144}$, which reduces to $\frac{B(450 + t)^{\frac{3}{2}}}{125(450 + t')\sqrt{h(t-t')}} = a$.

But this equation supposes no resistance besides contraction at the orifice at the fire-place; now the eddies, loss of heat, obstructions, and change of direction in the chimney, will diminish the velocity, and render a larger area necessary: making the divisor 100 instead of 125, will be a sufficient compensation in common cases; consequently,

$$\frac{\cdot 01\,B(450 + t)^{\frac{3}{2}}}{(450 + t')\sqrt{h(t - t')}} = a \text{ in square inches.}$$

From the effect of variation of temperature, it is evident that this equation has a minimum value for a, which will occur when $\frac{(450 + t)^3}{t-t'}$ is a minimum. Now by the rules of maxima and minima of quantities, this will happen when $t = 275 + 1{\cdot}5\,t'$: or when the external air is at 50°, that in the chimney will be 350, or 300° above the temperature of the atmosphere. Mr. Gilbert makes the difference of temperature which corresponds to the maximum, 333°. (Quarterly Journal of Science, Vol. XIII. p. 114.) In the case in the text, $212 - 52 = 160$, and $160 - 16 = 144 = t - t'$, the difference of temperature; hence, when $B = 2000$ cubic feet, $\frac{45}{\sqrt{h}} = a$ in inches; which is the same as the rule in the text, when the time is one hour. When the effective difference of tem-

If you require double the quantity of steam, the chimney should be double the size, if half the quantity half the size, and so of any proportion. Hence the importance of a damper to regulate the fire.

95. These calculations will shew how very small a chimney is required when the smoke is allowed to escape at so elevated a temperature; but if the effective difference between the temperature of the air in the chimney and that of the external air be only 40°, then this rule should be employed.—Rule. Divide 80 by the square root of the height of the flue in feet, which will give the area of the flue in inches, for a boiler producing the steam of a cubic foot of water per hour. And the opening to admit air to the fire should be in the same proportion as before.

perature is only 40°, which will be the case when the temperature of the chimney is 108°, and B = 2000 cubic feet, the external air being 52°, then, $\frac{80}{\sqrt{h}} = a$ in inches, which is the second rule in the text.

The area of a common chimney-flue is about 100 inches. Common chimneys are not in general very well constructed; they are seldom made smooth and hard, so as to be capable of resisting the action of a cleaning apparatus. Some years ago, I proposed a method of building them, by having earthen pipes fitted together to form the flue, and built into the wall. By this means a hard, smooth, and regular flue would be obtained; its form would be circular, and easy to clean by machinery. (See New Monthly Magazine for Dec. 1816, p. 416.) I understand that such flues have lately been executed in Scotland; and they have been recommended by Mr. Nash, in his Report to the Board of Works concerning climbing boys. (Phil. Mag. Vol. LIII. p. 106.)

The advantage of a high flue is so considerable, that the reader may be desirous of knowing to what height a chimney of a given base may be erected with safety, when it is inconvenient to stay it with braces; and as an approximate rule for this important problem is not difficult, I shall add one or two here.

If you wish to ascertain what base to give a square chimney shaft of uniform size throughout its height, divide 156 by the difference between 12,000 and 26 times the height in feet; and the square root of the quotient multiplied by the height in feet will be the side of the base.*

* I have shewn (in the art. Stone Masonry, Napier's Supp. to Ency. Brit. § 54,) that the strength of the wall in this case will be $A w d + 6 l R = f d^3$. Where d is the side of the base, supposing it to be square, A the solid content of the wall; $d^2 w$ the weight of one foot in height at the base, and R the stress on the wall acting at the height l from the base, f being the strength of a square foot of mortar. Suppose 52 lbs. on a square foot to be the greatest force of the wind; h the height of the chimney, and the side of the top to be to the side at the base as $n : 1$; then we shall have

$$l R = 52 h^2 d \left(\frac{2n+1}{6}\right), \text{ or } 6 l R = 52 h^2 d (2n+1).$$

Also, $A = \frac{h d^2}{3}\left(\frac{1+2n-n^3}{1+n}\right)$. Hence our equation becomes

$$\frac{h d^3 w}{3}\left(\frac{1+2n-n^3}{1+n}\right) + 52 h^2 d (2n+1) = f d^3.$$

$$\text{Or } d = \sqrt{\frac{52 h^2 (2n+1)}{f - \frac{1}{3} h w \left(\frac{1+2n-n^3}{1+n}\right)}}.$$

The value of f for good mortar is about 12,000 lbs. (Stone Ma-

Thus let the calculation be made for a height of 20 feet, then $26 \times 20 = 520$; and $12000 - 520 = 11480$; also $\frac{156}{11480} = \cdot 0136$, of which the square root is $\cdot 117$ nearly; consequently $20 \times \cdot 117 = 2\cdot 34$ feet, or 2 feet 4 inches.

When a chimney stack is not square, this must be the dimension of the least side.

If the chimney be diminished towards the top so as to be only half the diameter at the top that it is at the base, the rule will be, divide 104 by 12000, diminished by 32 times the height of the chimney in feet, and the square root of the quotient multiplied by the height in feet will give the side of the base.

sonry, Supp. to Ency. Brit. Table III.); and when the chimney is of the same size throughout its height,

$$n = 1, \text{ and } d = \sqrt{\frac{156\, h^2}{12000 - \frac{1}{3}\, h\, w}}$$

In tapering chimneys, a good proportion will be to make $n = \frac{1}{2}$, and in that case,

$$d = \sqrt{\frac{104\, h^2}{12000 - \cdot 42\, h\, w}}$$

The most usual proportion of solid wall for a given base will be $\frac{2}{3}$ of its area, therefore, w should be two-thirds of the weight of a cubic foot of the wall; in brickwork, this value of w is about 78 lbs.; consequently in brick chimneys of the same size through, out,

$$d = h \sqrt{\frac{156}{12000 - 26\, h}}; \text{ or } d = h \sqrt{\frac{6}{500 - h}}.$$

When they are diminished to one half d at the top,

$$d = h \sqrt{\frac{104}{12000 - 32\, h}}: \text{ or } d = h \sqrt{\frac{3\cdot 25}{375 - h}}.$$

I shall take as an example, a case where it is required to build a chimney 100 feet high to carry off the smoke of a steam engine; this being, as nearly as I can recollect, the height of one built at my native city (Durham) for preventing the injurious effect of the smoke from the colliery engine. By the rule $\frac{104}{12000-(32\times100)} = \cdot 01182$, of which the square root is $\cdot 109$ nearly, and $\cdot 109 \times 100 = 10\cdot 9$ feet, or 10 feet 11 inches nearly, for the side of the base, and consequently, $5\frac{1}{2}$ feet for the side of the top.

96. The depth of fuel to be on fire at the same time, is also to be considered; because, such a body of heat must be sustained as will keep up the supply of steam, and at its lowest state be sufficient to ignite the fresh fuel, without impairing its action on the boiler in a sensible degree. From my observations and experiments to determine this point, it appears that the depth of burning fuel should be about three or four times the depth of what is added at a time in feeding the furnace, that is, four times when you feed frequently, and three times when you feed seldom. And, according to the nature of the fuel, there will be a greater or less space wanted between the bars and the boiler.

But in the construction of steam apparatus, it will usually be desirable that the fire should not require much attention, and then a greater space must be provided, and the fuel applied gradually at each feeding, with the damper raised a little; and when a

feed to last the necessary time has been put on, the damper must be lowered to a slow draght, and the fire will require no attention till the feed be consumed.

97. Having now made those inquiries which regulate the dimensions of fire-places, we next have to consider their construction. The object is to confine the heat to the boiler; therefore, the slowest conductors of heat should be used; some metal work is absolutely necessary, but it should be avoided as much as possible. The space for the fire and seat of the boiler, it will be best to line with good fire-brick, built with fire-clay, with no more iron work about it than is absolutely necessary; that is, simply, the bars and a rim at the mouth where the fuel is put in at, with or without a door, as it may be thought best. When a door is not used, the space is to be filled with fuel.*

The rest of the brick-work should be built with hard, well burnt bricks; and in order to confine the heat to the boiler, it will be proper to leave cavities in the brick-work; the object should be to inclose the fire and boiler with a double wall, or one with a hollow space between: this cannot be completely effected, but may in a great degree. Morveau's maxim should be always kept in view, which is,

* In Mr. Watt's patent (1785) he made the fuel to answer instead of a door. (Rep. of Arts, Vol. IV. p. 226.) It was applied in a more effectual manner by Messrs. Roberton, (Phil. Mag. Vol. XI.) and subsequently by various people.

that "the fire-place ought to be insulated from all bodies that are rapid conductors of heat."*

A dead space U, Plates I. and II. fig. 1, 2, 3, and 4. should be left between the bars and the fire-place door, to prevent it being speedily destroyed by heat, or warped so as not to fit close. This space should be paved with strong fire tiles:† it is commonly covered with an iron plate, called a dumb-plate. The bars may be from one inch and a half to three inches deep, according to the size of the fire, the thickness about an inch, and the space between them about ⅝ths or half an inch. They are seldom made longer than two feet or two feet six inches, and in large fire-places two or three lengths are required

* Repertory of Arts, Vol. XVI. p. 225. old series.

† It appears to be a great disadvantage to place the fire too far in under the boiler; because it exposes it to a current of cold air every time of stirring the fire; neither is it any advantage to keep it so far out that the flame cannot play against the bottom of the boiler. Count Rumford shewed the best effect to be produced when the flame was caused to act directly against the boiler, with a properly directed blast, and not too intense. (Essays, Vol. II. pp. 37 and 73. (Some have imagined a greater effect would be gained by having the fire within the boiler. It is a very old scheme. (See Birch's Hist. Royal Soc. Vol. I. p. 173.) Smeaton adopted it for his experimental engine, (Reports, Vol. I. p. 225,) and Trevithick for his high-pressure engine. But the plan is not so good as might be supposed, because the generation of steam takes the heat too rapidly from the fuel for perfect combustion to take place. A fire-place, when the fuel is partially inclosed by slow conductors of heat, will always be found to answer much better. I do not know a more simple illustration of the effect of different conductors, than trying the effect of a blowpipe, first with a metallic and then with a charcoal support for the matter to be heated.

according to their size. These bars are put in so as to rest loosely upon cross bars, and, therefore, are easily taken out and renewed when it is necessary.

The area of the grating may be easily proportioned by this rule; viz. let it be one foot to burn $\frac{1}{8}$ of a bushel of coal per hour, 2 feet to burn $\frac{1}{4}$ of a bushel, 3 to burn $\frac{3}{8}$ of a bushel, and so in direct proportion to the quantity of fuel; and let the surface of boiler exposed to the effect of the fire, flame, and smoke, be 4 times the area of the grating.*

* This rule was given in the first edition of this work, but the reasoning on which it was founded was not exhibited. The only experiments we have on the quantity of heat given off by a hot body to water are two, made by Professor Leslie,* and in these there is a variation of effect depending on the excess of temperature, for the fluid ought to have been kept in motion to render the law (art. 38.) applicable. In a steam-boiler the fluid is in motion during the generation of steam, and hence we may be guided by the result of the experiment where the excess of temperature was greatest. And when the data of Leslie's 51st experiment are inserted in the Equation, art. 42, note, we have $0{\cdot}0138\,s\,(T-t) = \varepsilon$.

Now if we estimate the mean temperature of the mass of fire, flame, and smoke, at 800°, and the steam be 225°, we have $T-t = 800-225=575$. And as $\varepsilon=1127$, (by art. 18.) The equation gives $0{\cdot}0138\,s \times 575=1127$; or making the time of converting a cubic foot of water into steam one hour; we have $s=2{\cdot}7$ feet. That is, 2·7 feet of surface of boiler exposed to the action of a fire of which the mean heat is 800° will convert one cubic foot of water into steam in an hour; and as it requires a bushel of Newcastle-coal to reduce 10 cubic feet of water into steam, the surface for burning a bushel of coal per hour will be 27 feet: and this being the whole area exposed to the fire, a grating of about one-fourth of that surface will be sufficient. The text gives 32 feet

* Inquiry into the Nature of Heat, p. 344—346.

The same area will answer for either a slow or quick fire, but in a slow fire a greater depth of fuel is necessary. And also for equal bulks of any other fuel the same area will apply as for coals, but it will be obvious, from this rule, that the areas to produce equal quantities of steam, will be inversely as the power of the fuel. When the plan of the boiler is not circular, the extent of the grating for the fire, in the direction of the width of the boiler, may be about one-half or two-thirds of that width. Whether this be the length or width of the grate, will depend on the place of the fire-place door; but it will always be best to have the door at the end of the boiler for long boilers.

98. The place and action of the damper is next to be considered, for it is one of the most important parts of the apparatus of a close fire-place, as a register to the ash-pit is of an open one.

The best place for the damper is immediately after the smoke quits the boiler: it should be left to the management of the fire-man, and marked with divisions at the place where it is moved, so that he may know exactly the quantity of opening there is into the chimney at any time. A self-acting damper may easily be constructed, but I cannot recommend the use of one for a steam apparatus.

When it is moved in a vertical direction by a balance weight, which is the usual method; the

for the surface of boiler, and 8 feet for the grating to suit for the ordinary case of burning a mixture of coke and coal.

damper should be of sufficient weight to render its action certain. In the plates (I. and II.) it is shewn as done to move horizontally.

99. Doors for the fire-places are to be contrived so as to shut as close as possible; in order to render them more perfect in this respect, Count Rumford made double doors; these, however, are very subject to get out of order; and, consequently, strong single doors of wrought iron are most commonly used. Mr. Atkinson has considerably improved the single iron doors, by having a hollow cavity formed by a box of cast-iron rivetted to the inside of the door: the depth of the sides of the box makes the door so strong that it completely prevents warping, and the hollow space of confined air prevents the escape of heat.

A door of cast-iron, balanced by a weight, in the manner of a sash-window, will be found convenient; it is much more easily opened and shut, is more out of the way when open, and shuts closer, than a door with hinges; and when any thing is to be done at the fire, a smaller opening is required. See fig. 3 and 4, Plate II.

The mode of construction which I think best is shewn in Plate I. A stop prevents the door being opened beyond a certain angle, which renders it impossible to throw the coals over the fire. The stoker should fill the dead space U, and then no heat will escape at the door; and when the door is also shut, it will completely stop the entrance of air. The fuel will be gradually heated, ready to

enter into combustion when pushed forward by the stoker, and a new supply of fuel should then be added in the plaee of that which has been thrust forward into the fire. The gases which distil from the fuel having to pass over the red-hot embers which are supplied with air from the ash-pit, will generally be wholly consumed in passing the throat of the chimney.

Apparatus for the Boiler.

100. These contrivances consist of a feeding apparatus, safety valves, steam-gauge, gauge-cocks, and man-hole.

Feeding Apparatus.—The use of the feeding apparatus is to supply the boiler with water, in order to eompensate for that which is converted into steam. The feed-pipe is shewn at W L, fig. 4, Plate II. The lower part of this pipe is turned at the end to prevent steam rising through it. Where it passes through the top of the boiler, it is made steam-tight, and fixed in a vertical position. The top of the pipe terminates in a small cistern head, L, which is kept supplied with water from a large cistern, N; and at the bottom of this small cistern there is a conical valve opening upwards, connected by a ehain to a lever, P, which turns on a centre, with a wire, H, attached to the opposite end. This wire passes through an air-tight stuffing box to a flat stone in the boiler; whieh is so balanced by a

weight, on the opposite end of the lever, as to float on the surface of the water.

Its action is performed in this manner: When part of the water is evaporated from the boiler, the stone float descends with the water's surface, and consequently raises the conical valve; now, the small cistern-head, L, being kept constantly full of water, by a pipe from the cistern N, as soon as the valve is raised, water enters the boiler, and when it is filled to the proper level it raises the stone float and shuts the valve, till a repetition of the operation becomes necessary.

The principal circumstance to be attended to in the construction of this apparatus, is, to make the height of the water in the cistern N sufficient to balance the strength of the steam. For if this height be too small, the water in the boiler will be forced up the feed-pipe by the pressure of the steam, and be driven out at the valve. Therefore when this height is correctly arranged for the greatest strength of steam it is proposed to employ, and the valve is of sufficient size, (see art. 103.) this pipe answers the purpose of a safety valve; and in boilers for steam apparatus, where the stop-cock of the steam-pipe is made so that it cannot be perfectly closed, no other safety valve is necessary.

Now the water in the pipe will be so increased in temperature, that 2·4 feet in height will be equivalent to the pressure of steam of 1lb. to the inch above the pressure of the atmosphere. Therefore, if you work so that the column may exceed the actual pressure required by a twenty-fifth part—

for 1 lb. per square inch N R should be $2\frac{1}{2}$ feet.

2 lbs.	N R	5
3 lbs.	N R	$7\frac{1}{2}$
4 lbs.	N R	10

The rate of increase is easily followed, but it is not desirable that stronger steam than 4 lbs. to the square inch should ever be employed ; because with an increase of risk it will cause an increase of expense in every part of the apparatus, with an increase, rather than any saving of fuel.

By arranging the column of water by this table it will prevent accident from too great strength of steam, for the steam will always blow through the feed-pipe as soon as the pressure exceeds the head of water in the cistern; with this view the part of the pipe L W may be kept larger, and also the valve. And an open tube, O, will allow air to enter if a vacuum be formed, or water to escape whenever the pressure is too great.* (See art. 103.)

The cistern-head L, should be as shallow as convenient to supply water to the boiler. A more simple kind of feed apparatus is shewn in Plate I.; the depression of the stone float opens a stop-cock in the pipe from the cistern; the height of the cistern being regulated as for the preceding method.

101. *Safety Valves.*—Safety valves are of two kinds, *internal* and *external*. An internal safety valve is to prevent the pressure of the atmosphere

* It might be called a tube of safety, from its similarity to that which chemists describe by that name.

crushing in the sides of the boiler or pipes, when a vacuum is formed by a sudden condensation of the steam.

An external safety valve is to prevent the bursting of the boiler or pipes, from the steam becoming too strong. In many instances precautions may be taken in steam apparatus of a very simple kind, which render the addition of these valves of very little importance. One of the precautions alluded to, consists in forming the cock for letting the steam into the pipes so that it cannot be perfectly closed; and so far from this being an inconvenience, it is very much better to let the pipes become partially warmed by a slow escape of steam, before the cock be wholly opened.

102. The internal valve is only necessary when the boiler and pipes are of such thin materials and imperfect form, that they would collapse under a pressure of 14 lbs. on the square inch. It is usually made in the manner shewn by fig. 5, Plate II. where V is the circular conical valve opening inwards, and balanced by a weight W at the opposite end of the lever. It is commonly placed on the plate which covers the man-hole; but may be on any other convenient part of either the boiler or the steam-pipes.

103. An external safety valve consists of a cylindrical box, containing a valve which rests in a conical seat; and is loaded so, that when the steam exerts a greater pressure against the surface of the

valve than 4lbs. upon a square inch, it opens and allows the steam to escape by a tube into the chimney.

It will be obvious that the safety valve should be of such a diameter that the steam may escape as quickly as it can be generated by the fire under the boiler; for, with a less aperture the steam will accumulate, and the pressure tending to rend the boiler will increase, even after it has become sufficient to raise the valve. And as through the continued action of the fire there is no knowing to what extent the pressure or force of the steam may increase, some rule for the area of the valve is necessary.

When the pressure is not to exceed 4lbs. on the square inch above the pressure of the atmosphere, and the greatest quantity of water the boiler could evaporate in an hour is known; divide the number of cubic feet of water that the boiler would evaporate in an hour by 5, and the square root of the quotient is the least diameter that should be given to the safety valve or safety pipe.*

By lifting at the handle of the valve, it is easily known whether it be in order or not; and when it is used, the stoker should be directed to examine its state frequently.

104. *Steam Gauge.*—It is sometimes desirable that there should be a steam gauge, to shew the state of the steam in the boiler. The common steam gauge consists of a bent tube of iron, attached to

* See the investigation, art. 127.

and communicating with the boiler or pipes: it contains a portion of mercury, which carries a float in the open leg, to indicate the force of the steam. It is, however, very seldom in order when made in the common manner; and it is very little required for steam apparatus; but for the use of those who are curious in these things, I will describe a simple contrivance of mine for avoiding the defects of the steam gauge.

105. *New Steam Register.*—The pressure of the steam is to be measured by the flexure of a circular plate of gun-metal: this plate being fixed between two flat rings of metal, and made to form a part of the boiler. The pressure of the steam on one side of the plate raises it in the centre, and moves one end of a lever, while its other end points to the divisions of a graduated arc: the fulcrum of the lever, and also the graduated arc, are upon a bridge across the upper ring of metal. When the thickness of the plate is proportioned to the strain, so that it shall never tend to separate the metal with a force greater than 5,000 lbs. upon a square inch, it will not be liable to get out of order by use.

106. *Gauge Cocks.*—In order to have a more certain knowledge of the quantity of water in the boiler, two pipes with stop-cocks are fixed in it. One of the pipes terminates a little above the level at which the water ought to be in the boiler, and the other a little below it. Consequently, if, when these cocks are opened, the one pipe gives out

steam and the other water, all is right. If they both afford water there is too much water in the boiler; if they both afford steam there is too little.

These gauge cocks are shewn at G G fig. 2, Plate I; and fig. 4, Plate II.

107. *Man-hole.*—The man-hole is merely an oval hole, with a cover for opening the boiler to examine it, or clean it out, as may be necessary. See M in fig. 2 and fig 4. But in a simple steam apparatus it may be applied to other purposes.

In the first place we wish to make it unnecessary to have two safety valves; and also make it so that the cover may be taken off and replaced with greater facility.

Let the cover for the man-hole be a kind of cup-formed vessel of cast-iron, (see fig. 6, Plate II.) to invert into a double rim of the same metal. This rim is to be firmly screwed to the boiler; and to have two standards, with holes of a determined size, to receive a bar of cast iron; which will, when wedged down at the ends, press upon a fulcrum in the centre of the cover.

The bottom of the groove wherein the cover rests should be lined with a regular thickness of hemp, which should be kept wet. Or a very soft metal, as lead, for example, may be run in; and the edge of the cover being made thin, it will adapt itself so closely when the wedges are driven, as to be steam-tight.

Now we can easily adapt such a size for the cast-iron bar, that it will break whenever the steam

exceeds a certain force. And another circumstance gives this species of safety valve some advantage; which is, that as soon as the steam exceeds its proper strength, by the flexure of the bar the cover will be raised and allow steam to escape. If the section of the cross bar be made square at the middle of its length, and the aperture be circular, then the cube root of the force of the steam in lbs. above the pressure of the atmosphere, multiplied by one 34th part of the diameter of the aperture, will be the side of the bar in inches. Let us suppose the diameter of the aperture to be 17 inches; and that the cover should open if ever the pressure of the steam should be 8 lbs. above the pressure of the atmosphere. In this case the cube root of 8 is 2; and $2 \times \frac{17}{34} = 1$, or the bar should be one inch square.* The strongest iron I have ever tried would not allow the pressure to become 9 lbs. on the inch, and the weakest would not break at 7 lbs.

* Those who would wish to study the principles of making these calculations, may consult my Essay on the Strength of Cast Iron and other Metals.

CHAPTER VI.

OF THE APPARATUS FOR DISTRIBUTING STEAM.

"In contriving machinery for any purpose, it is indispensably necessary to be acquainted with the nature of the mechanical operation to be performed." RUMFORD.

108. WE have, in the first place, to consider the effect it is desirable to produce; for in some cases it will be desirable to afford the greatest degree of heat with the least quantity of surface, and to heat quickly; in others, it will be requisite that the vessels should be capable of retaining and giving off heat a considerable time after the steam ceases to flow into them, and also to yield heat gradually when set to work; in a third kind, some degree of ornament or convenience of form may be essential. If the most effectual means alone were to be described, our inquiry would be confined to few objects; but for those who are less acquainted with the objections to some materials and modes of distributing steam, it will be useful to enter more into detail. In so doing, the following order will be adhered to; materials for vessels and pipes; surface of vessels, and space for steam; thickness and form of vessels; allowance for expansion, and mode of joining; cocks, valves, syphons, and other appen-

dages to vessels. The distribution of pipes, &c. being determined by the nature of the place to be heated, will be best considered in the chapters on heating dwelling-houses, hot-houses, &c.

Of the Materials for Pipes and Vessels.

109. It is most usual to employ cast iron for steam-pipes and vessels; and it is justly esteemed preferable to all other metals for this purpose, because it does not, by being heated, exhale any thing injurious; it may be formed of any shape that is most convenient, and it is strong and durable.

110. Tinned iron has also been used in many instances, and chiefly because it is less expensive than cast iron; but it is also much less durable. Tinned iron gives off nothing injurious when heated, but the vessels formed of this material should be provided with valves, to prevent them collapsing when a vacuum takes place in the vessel.

111. Copper has very frequently been used for steam-vessels and pipes; it is, however, objectionable, because it exhales a peculiar odour when heated, which is neither agreeable nor healthy. This objection to the use of copper, renders it unnecessary to dwell upon its comparative advantages, at least where rooms are to be heated; but in drying rooms it will be required, because iron would injure the linen, &c. Copper is more expensive than tinned iron, but it is much more durable.

In copper pipes it will be necessary to place valves to prevent them collapsing.

The condensed water which passes through copper pipes, should not be used for domestic purposes.

112. Lead is often employed for pipes to convey steam, but it is wholly unfit for that purpose, because the heat of boiling water expands it beyond its power of restoring itself; and consequently, pipes of lead become longer every time they are heated, and ultimately fail. If it were not for this defect, it would be an exceedingly convenient and economical material for many parts of a steam apparatus.

113. In order to supply, therefore, the place of lead for small pipes, it will be necessary to use wrought-iron ones, such as are made for gas-pipes. They are not more expensive, and they are durable, safe, and convenient. They will be found sufficient to convey steam to vessels or larger pipes in many cases, and excellent for connecting pipes.

114. Zinc pipes I have not heard of being used; but from the brittleness of zinc, it would break all to pieces if there were any partial vacuum formed in the pipes: and it also oxidizes considerably at a high temperature, and therefore would not be very durable.

Of the Surface of Vessels and Pipes, and the Space for Steam.

115. It had been known for a considerable

time, that the colour of the surface of a body renders it more or less sensible to the effect of heat; for example, that a black body would feel hotter than a white one, when equally exposed to heat.* But it has lately been experimentally proved, that a hot body with a blackened surface diffuses more heat in a given time than a bright metallic one; every other circumstance being the same. And also, that the nature and even the form, of the surface, is a cause of some difference of effect.

For these results we are indebted to the ingenious and interesting researches of Professor Leslie. They are described in his "Experimental Inquiry into the Nature and Propagation of Heat." But these experimental researches not having been made exactly under those conditions which are most convenient for our purpose, in estimating the effect of any particular surface, it was necessary to make new ones, rather than rest too much on theoretical principles. (See Chap. III. art. 42.) The proportion which one surface, or one colour, bears to another in its power of giving off heat, as determined by Professor Leslie's Experiments, will be best given in this place, where it is our chief object to compare the effect of surfaces and colours. A surface coated with lamp-black, appears to be the most effectual in giving off heat, and a bright surface of tin the least; therefore, considering the effect of

* Sir Isaac Newton has assigned a reason for this effect of black bodies in the sixth query at the end of his Optics; and Bishop Watson ascertained that blacking the bulb of a thermometer would cause it to rise sooner.

the tin to be unity, or 1, it will serve as a standard of comparison. Now, according to experiment, it appears that a globular vessel of planished tin, four inches in diameter, filled with hot water, cooled down 10 centigrade degrees in 156 minutes. When the same vessel was painted on the external surface with a coat of lamp-black, it cooled the same number of degrees in 81 minutes;* that is, the times of giving off the same quantity of heat, are as 1 : 0·52, or nearly as 2 is to 1; or bright tin requires double the time to dissipate the same quantity of heat. But in another experiment, where the only difference was a greater excess of temperature in the hot water, the times were as 1 is to 0·66.† The times to produce the same effect with a surface of bright tin, and one of tin rubbed with quicksilver so as to give it a splendent lustre, were as 1 : 0·96; but when sufficient quicksilver was added to render the surface a matted white, the times were as 1 : 0·89.‡ When bright tin was compared with bibulous paper soaked in olive oil, the times were as 1 : 0·55 nearly; but a thin film of oil did not reduce the time so much, the ratio in that case being as 1 : 0·83.|| Rubbing the surface of the tin with fine sand paper shortened the time of cooling, and coarse sand paper still more; in the latter case the times were as 1 : 0·91.§ Different thicknesses of the same substance altered the rate of cooling; for the time for bright tin being

* Leslie's Inquiry into the Nature of Heat, p. 268, Expt. 43.
† Idem, p. 274, Expt. 45. ‡ Idem, p. 332, Expt. 48.
|| Idem, p. 334, Expt. 49. § Idem, p. 335, Expt. 50.

1, a coat of isinglass size, 10,000th of an inch thick, reduced it to 0·7; a coat double that thickness reduced the time to 0·615; and a coat of 10 times that thickness reduced it to 0·53.*

Count Rumford had previously ascertained, that a thin covering of linen cloth accelerated the cooling of a brass cylinder in the ratio 1 to 0·665;† we might with apparent reason, have formed an opposite conclusion. But where heat is to be confined, it must be by a slow conductor of considerable thickness, or alternate strata of different kinds of matter, as we shall explain in treating of confining heat. (See art. 134.)

116. There is reason to conclude, that mere colour is not of material importance, for it appears that a thick coat of isinglass size, was as effectual as lamp-black. This remark is the more required, because in cases where the heating apparatus is to be ornamental, it will not be necessary to adhere to any particular colours, but to adopt those which harmonize best with the place.

117. In respect to the space for steam, when the supply is to be continual, it may be remarked that it should not be considerable on the one hand, nor so small that the steam will not flow freely to supply every part on the other. If you make the space too large, the distributing apparatus will be long in filling; if it be too small, the steam

* Leslie's Inquiry, p. 336, Expt. 51.

† Thomson's Chemistry, Vol. I. p. 36.

will flow with difficulty. In pipes, for example, their diameter should never exceed six inches, nor ought they to be less than three inches where the quantity is considerable. The space for steam, it should be recollected, is quadrupled by doubling the diameter of the pipe, while the quantity of surface, on which the effect of the pipe depends, is merely doubled. When the pipes would exceed six inches, to gain the necessary quantity of surface, then it would be better to have two pipes; and with a very little extra trouble it can be arranged so that either both the pipes, or only one of them, may be heated, as occasion may require. This power of increasing or diminishing the quantity of heating surface will be found useful in many cases.

But where the condensed water is to collect in the pipes, and to supply heat when the steam has ceased to flow, large pipes will be best.

When heat is to be slowly communicated, and to decline slowly, the pipes may be made of larger diameter, and the interior of them filled with broken flints, clean pebbles, or the like. By adopting this method, the pipes would not afford a full supply of heat till the flints, &c. had absorbed their specific quantity, and this quantity would remain to be slowly given out after the steam had ceased to flow from the boiler. In providing artificial heat for plants this method would be useful.

Of the Thickness and Form of Vessels for Steam.

118. It has been imagined that the thickness of

steam vessels, is of little importance; but it will be best to inquire how far this notion is correct, and to follow the conclusions drawn from reasoning, in preference to opinion.

The thickness may be considered, as it affects the supply of heat, and as it is sufficient for strength.

The thickness of any substance, it may be proved by experiment, renders it incapable of assuming a uniform temperature, when the heat is applied at one side only; and the same conclusion is obvious when we consider that no body whatever is a perfect conductor of heat, and consequently, cannot become uniformly heated, by heat acting on one of its sides. In a very thin plate the difference must be very small; but by increasing the thickness it may be rendered very considerable, and may be varied at pleasure, by proportioning the thickness to the effect. But it is the temperature of the external surface of a steam vessel which regulates the supply of heat; and the greatest supply will be afforded when the thickness is not greater than is absolutely necessary for strength: that is, as far as regards a maximum supply of heat, the thinner the better.

Under some circumstances, a rapid diffusion of heat is not desirable, and consequently, thickness is an advantage. Such, for example, are forcing-houses, green-houses, &c. The quantity of heat iron contains, is too small to render a mass of it useful as a reservoir of heat, and such a reserve may be obtained at a less expense in the manner proposed in art. 117.

119. The thickness required for strength depends much on the form of the vessels. The most usual and most useful kind, are long tubes or pipes, and those of cast iron will be of sufficient strength when cast as thin as they can be formed, so as to be perfect. This can be done with somewhat less than 3-8ths of an inch of thickness. The cylindrical form is best, because strongest; more surface may easily be given, but will be rendered less effective by increase of thickness.

In halls, stair-cases, anti-rooms, galleries, &c. pipes cannot be employed with propriety, unless concealed, as described in fig. 12, Plate III.; and therefore, other forms of vessels may be used for producing the same effect. If the cavity between two hollow cylinders, the one inserted within the other, be filled with steam, it will offer a considerable extent of surface, without occupying much space, and may be made as a pedestal for a bust or figure. Even figures themselves might be receptacles for steam, and be the means of distributing heat: also, ornamental columns, pillars, vases, and the like, may be adapted to the same purpose.

Of the Expansion of Pipes and Vessels, and the Mode of Joining them.

120. In the Table of Expansion, Table III. art. 218. the expansion of different materials will be found for a change of temperature of 180°. Now, this change will be as great as need be provided for

in the construction of steam apparatus, because the mean heat of the pipes or vessels is less than 212°, and they are seldom likely to be cooled below 32°.

It will be seen by the table, that the length of a cast-iron pipe being 1 at the freezing point, it will be 1·00111 nearly at the boiling point; this is somewhat more than 1-8th of an inch for every 10 feet in length of pipe, but sufficiently near for us to be guided in practice by that allowance.

The expansion of malleable iron is ·001258; and 1-8th of an inch should be allowed for expansion for every 8 feet in length. The allowance for tinned iron pipes should be the same.

The expansion of copper is ·0017, therefore, 2-10ths of an inch should be allowed for expansion in every 10 feet in length.

Lead expands still more than copper, as its expansion is ·002867. The allowance for the expansion of lead approaches near to $3\frac{1}{2}$-10ths of an inch for each 10 feet in length. But though lead pipes are not proper for steam, they may often be usefully employed to return the condensed water to the boiler; and in that case, 1-5th of an inch for every 10 feet will be sufficient.

These quantities I have endeavoured to express in terms most easy to be remembered, because the quantity to be allowed must be ever present in the mind both of the designer and the workman. No part of an ordinary building is capable of resisting the expansive power of an iron steam-pipe, and

where there is an adequate resistance at the extremities the joints or solid pipe must fail.*

In order that the pipes may be freely at liberty to move as they expand, they should be supported by rollers.

121. Horizontal steam-pipes, being hotter at the upper than the under surface, the consequent unequal expansion gives them a slight curvature; but the quantity of curvature thus produced, being less than the material will bear without permanent derangement, its effect need not be regarded.

122. In heating new buildings by steam, vertical pipes have been employed; and, with an idea of economy, these pipes have been made to answer as principal supports for the buildings. The impropriety of this mode of construction will be obvious, when it is considered that the quantity of expansion is sufficient to disunite the floors from the external walls, so as to render them wholly dependent on iron ties for connexion; also, the pipes must be thick for strength, and therefore, they will afford less heat in proportion to the quantity of surface, and be longer in acquiring the proper temperature. (See art. 118.) It appears to me to be a considerable advantage, in all cases, to have the heating

* The motion produced by the expansion of pipes has been ingeniously applied to regulate the admission of steam into the pipes, by Mr. H. Creighton, of Glasgow, for which he obtained a patent in 1818. (See Repertory of Arts, Vol. XXXIX. p. 85.) It is also made the means of opening air-valves.

apparatus distinct from the fixed parts of a building, so that they may be renewed, altered, or repaired, without injury to the substantial parts of the structure; this, with the considerations above mentioned, more than compensate for any extra room required to have the apparatus distinct.

Joining Pipes, &c.

123. The use of cast-iron pipes and vessels is often avoided on account of the difficulty of joining them; but this difficulty is not so considerable as it is imagined to be. The joints are to be steam-tight, and it will always be an advantage that they should be slightly elastic. The latter property will render the connexion less liable to be injured by accidents. In order to make the joints tight, they should be contrived so that the parts can be forced together; for in joints where the parts are not held together by force, the expansion, contraction, and motion of the pipes, &c. will soon render them incapable of retaining steam. An attention to these conditions renders it easy to determine what kind of joints are best fitted for steam apparatus.

124. The usual, and it is esteemed the best, mode of joining pipes, &c. is by flanches, as shewn in figs. 7 and 8, Plate III. In the joint should be inserted a flat plait of slightly twisted hemp yarns, which has been previously saturated with stiff white lead paint. The width of the plaited hemp is determined by the width of the joining surfaces; but it

will be an advantage not to make it thin, because then the joint will have less elasticity. If a little red lead be mixed with the white lead paint, it will dry sooner and become considerably harder. And it may also be remarked, that mill-board* may be used in the place of hemp.

As there is the means of forcing these joints close by means of the screws *a*, *a*, *a*, *a*, through the flanches, there is very little difficulty in making them steam-tight.

125. There is, however, an objection to this mode of joining pipes, which is, that they continue a considerable time to give off a disagreeable effluvia in consequence of using oil: and therefore, for dwelling-rooms some other process seems required. If the ends were ground even, and a hoop of tin of about 3-8ths of an inch thick, were put in the joint, instead of the hemp, and the screws made tight, with the metal as cold as convenient, it would make a secure joint. Lead is too compressible to be used instead of tin, and it contracts permanently, hence, I have understood, it has never been found to answer.

Some use iron cement† for the joints, but where

* The mill-board dipped in white lead Messrs. Loddiges esteem the best.

† Iron cement is formed of borings or turnings of cast iron, 40 parts by weight, mixed with powdered sal ammoniac (muriate of ammonia) one part, and half a part of sulphur. The iron borings should be free from rust or dirt, and coarsely pounded. To use this cement, mix the ingredients together, and moisten them

white lead and hemp, or mill-board can be used with propriety, it is preferable.

126. The joints, called spigot and faucet joints, commonly used for water pipes, are not so well adapted for steam-pipes; because there is no provision for holding the parts together. The same defect is common to the various kinds of thimble joints.

Pipes may be formed to any regular curve if moulded in short lengths, and also to return at right angles, or to branch in any direction.

Wrought-iron pipes are joined by making the lengths that are to be put together each to screw into a piece of pipe of larger diameter. They may also be screwed into cast-iron pipes, cylinders, &c. so as to serve as branch pipes, connecting pipes, and the like. A nut for drawing the joint tight is in some cases thought necessary.

It may be remarked, that in joining two different metals, by screwing the one within the other, the metal which expands most by heat should always be made to screw into the other metal, otherwise there will, most probably, be an escape of steam as soon as the pipes become hot. For a like reason, cocks should never be made of two kinds of metal; neither

slightly with water, and force the composition into the joints with a caulking chisel and hammer; after which, the joints should be tightened as much as possible. If more cement be made at one time than is wanted, it will spoil. When the materials are good, and the mixture properly made, this cement will become very hard in a day or two.

should soldered joints be depended upon; for the inequality of expansion in all such cases affects the joints.

Where, in consequence of turns and angles, other modes of avoiding the effect of expansion will not apply, the ingenious and simple one adopted by Count Rumford may be used. It consists in joining the pipes with a drum of thin copper, of sufficient diameter to allow of the quantity of expansion to compress and extend it without injury. These drums were used for the steam-pipes applied to warm the lecture room at the Royal Institution.

A similar effect may be obtained by connecting the pipes by a short length of smaller pipe, to slide in a stuffing box in one of the pipes; but I use the drum in preference.

127. It is sometimes necessary to place the boiler at a distance from the place where the heat is to be applied; and in order that as little heat may be lost by the way as possible, the pipe called the main, for conducting the steam from the boiler, should not be larger than is sufficient for that purpose. The greatest quantity of steam will be required when the spaces to be warmed are at a low temperature. If they be at 30°, then each 150 feet of surface of steam pipe will condense a cubic foot of water per hour; (art. 46. note,) and as the whole quantity that would be condensed by a given surface is easily ascertained, the diameter of the main pipe may be found by multiplying the number of cubic feet of water condensed in an hour by 0·3 and the

square root of this product is the diameter of the main pipe in inches.*

Example.—Let the surface of steam-pipe be 960

* Let h be the height in feet of a column of steam equivalent to the excess of the force of the steam above the pressure of the atmosphere; then $5\sqrt{h} =$ the velocity it would generate in feet per second, when reduced for the effect of contraction at the aperture; and the velocity in feet per hour is $5 \times 60 \times 60 \sqrt{h}$. If d be the diameter of the aperture in inches, then $\frac{\cdot 7854\, d^2}{144} =$ its area in feet; and $\frac{5 \times 60 \times 60 \times \cdot 7854\, d^2 \sqrt{h}}{144} =$ the cubic feet of steam that would flow through the aperture in an hour. But it is somewhat more convenient, for our purpose, to measure by the quantity of water converted into steam per hour; and let c be that quantity in cubic feet, and $b\,c$ its bulk in the state of steam, whence $98{\cdot}175\, d^2 \sqrt{h} = b\,c$, or very nearly $\frac{\cdot 0102\, b\, c}{\sqrt{h}} = d^2$. We have now to determine the value of h, and if w be the height of a column of water equivalent to the excess of force of the steam, it is $h = b\,w$, and $\sqrt{h} = \sqrt{b\,w}$. But the velocity derived from this value of h must be reduced, because a column of air of the same base is to be displaced, which is only 830 times the bulk of water, therefore we must substitute $\frac{830}{b}\sqrt{b\,w}$ for $\sqrt{h}$; and our equation becomes $\frac{\cdot 0102\, b^2 c}{830\sqrt{b\,w}} = d^2$; or $\cdot 0000122720 \sqrt{\frac{b^3}{w}} = d^2$. When the steam is at 220° degrees, $w = 6{\cdot}25$ feet, and $b = 1470$, (see Table VI. art. 221.) $\cdot 248\, c = d^2$. This formula will apply to the area of pipes for mains; but it will be safer to make it $\cdot 3\, c = d^2$, lest too low a value of d should be obtained. For safety pipes and valves we may take the temperature 225°, and then $w = 10{\cdot}4$ feet, and $b = 1342$, consequently $\cdot 187\, c = d^2$. In the rule for safety valves it is made $\cdot 2\, c = d^2$, or $\frac{c}{5} = d^2$.

feet; then $\frac{960}{150} = 6{\cdot}4 =$ the number of cubic feet of water that would be condensed in an hour; and $\cdot 3 \times 6{\cdot}4 = 1{\cdot}92$, of which the square root is nearly 1·38 inches the diameter of the main pipe.

128. In every part of the distributing apparatus it is necessary to give the pipes as much inclination as will prevent any considerable quantity of water collecting; for when steam is admitted into the pipes, &c. and meets with a great surface of cold water remaining in them, it condenses the steam so rapidly as to endanger the boiler and pipes, should they not be firm enough to resist the pressure. When it is possible to have the boiler at a lower level than the pipes and other steam vessels, it is best to return the water of the condensed steam into the boiler again, because it not only saves fuel, but also requires only a small supply of fresh water; an object worthy of attention where water is scarce.

129. But it will be desirable in some cases to allow the water of condensation to collect in the pipes, and to continue to give out heat after the steam has ceased to flow into the pipes. Stop-cocks may then be employed for letting the water out of the pipes, and the same cocks will serve for letting out the air as the pipes fill with steam; but when the water is returned into the boiler, we cannot reserve the advantage of this supply of heat. The stop-cocks it will be the fireman's duty to open

always before the steam be admitted, and to close as soon as the pipes are filled with steam.

130. It is most common to have self-acting apparatus for taking off the water of condensation; of these, the most certain in its action is the inverted syphon.

A B C, fig. 9, Plate III. represents a syphon of this kind. The pipes are fixed, so that A is the lowest point; then any quantity of water that may collect in the pipe, will flow into the syphon at A, and run to waste or otherwise at C. The depth A B should not be less than is equivalent to the force of the steam in the pipes; therefore, it should be determined by the table we have given in art. 100. Thus, when the steam is worked at 4lbs. per square inch, the column of water B C should not be less than 10 feet, and even with this pressure there will be considerable oscillations, unless a valve be placed at some point, D. When the legs are both filled with water and at rest, this valve should be open, and constructed so as to close whenever the water had a tendency to return into the pipe.

The syphon should be large enough to take away all the condensed water with ease; but it should not be too large, because there will be a loss of heat in the leg A B, from its being filled with steam;* and

* When A is 6 inches above the level of C, the pipe will be always clear of water if $\sqrt{\cdot 0408\, c} =$ the diameter of the pipe in inches, where c is the quantity of water condensed in an hour in cubic feet.

in all cases the syphon should be carefully protected from freezing.

In connexion with the syphon, it is usual to place a cock for letting the air out of the pipes when the steam is let in; this cock and its pipe is shewn at E. It is kept to range with the lower part of the pipe, because, air being heavier than steam, it therefore occupies the lower part.

In fixing these things it should be recollected that the pipe will move by the expansion when heated. This expansion may be made the means of opening the cock E to let out the air.

131. When it is not convenient to get depth for a syphon, a steam trap or valve, to open by a float ball is employed; and perhaps with the most convenience in this manner. Let B C, fig. 10, be a square box attached to the end A of the steam pipe, and D a hollow copper cylinder fixed to a conical valve E. When steam is condensed, the square box will fill with water, which will float the hollow cylinder; consequently the water will escape by the pipe F into the drain, at all times when the quantity in the box is greater than is required to float the cylinder; when there is less than will float it, the valve will close.*

* The principle is described in Buchanan's Essays on Fuel. Another, but less simple method of allowing the water to run off, is described in the Transactions of the Society of Arts, Vol. XXXV. p. 179. The latter might be used when a safety valve in the pipes

The valve should not be larger than is required to take away the water, and in proportioning the ball, the pressure of the steam on the valve should be taken into the calculation. In this case also a stop cock, S, to let out the air while the pipes are filling with steam, will be necessary. The motion of the pipes when expanding by heat may be applied to turn it.

132. But the water ought to be returned to the boiler, in all cases where we do not retain the whole of it in the pipes, to afford a supply of heat after the fire is burnt out; and the most simple and obvious plan of doing this is to give the pipes a descent to the boiler, where it can be placed at sufficient depth for that purpose. This arrangement is not, however, the best, because a free circulation of steam through the pipes does not go on so well, on account of the returning water condensing it.

It is found better, therefore, to have a small pipe for the purpose of returning the condensed water. The steam pipes proceeding in the nearest course to the highest point where steam is required, and then descending to the lowest, from which the small condensed water pipe returns the water to the boiler. Unless you want heat in the places through which this small pipe is to pass, let it be surrounded with slow conductors of heat, so that as little as possible may escape.

is wanted; as whenever the steam exceeds a certain pressure, it must escape.

133. All this arrangement is however often useless, for we cannot in every instance get the boiler at a sufficient depth below the lowest place where we require heat. But, returning to art. 101, it will be seen that steam is capable of supporting a column of water of a determinate height; therefore, while we can get to a depth within the range of this height, we can return the water to a higher level in this manner:—

Let A be the cistern to which it is to be returned, fig. 11, and B the lowest part of the steam pipe, and A B a pipe from the steam pipe to the cistern, with a valve C to prevent the water forced into this pipe, by the pressure of steam in the steam pipe, from returning. That this apparatus may perform the intended effect, the point D must be above the level of the water in the cistern, and the height D B not greater than 9 feet when the pressure of steam is 4lbs. upon a square inch.

Of Confining Heat.

134. In conducting heat to the place where it is to be applied to some useful purpose, the art of preventing it being lost in the passage, becomes an interesting subject of study. Rumford and Leslie * have ascertained the principles on which this art depends. The former shewed the method of confining heat by slow conductors; the latter the effect

* Rumford's Essays, and Leslie's Inquiry into the Nature of Heat.

of alternation of surfaces; each has its peculiar value, but practice is in all cases a combination of both methods.

The slow conductors, applied to confine the heat of pipes, should be dry, and the access of moisture to them should be guarded against; for the most of these bodies possess the property of absorbing water, and retain it with much force; but as soon as they become damp their conducting powers are much increased. The substances which will apply to this purpose are chaff, pounded charcoal, ashes, dry saw-dust, bran, lime in powder, brick-dust, &c. With these the pipe or vessel, which is likely to lose heat, should be surrounded to a considerable thickness; this thickness will depend on the temperature of the hot body, and should be from two to three inches, for steam pipes. The slow conducting matter should not be closely pressed into the space it is to occupy; and in some instances may be confined by a wooden case; but where damp is apprehended the case should be water-tight; and may be of metal, stone, or other convenient matter. In Plate I. and II. the application to confine the heat of a boiler is shewn.

Solid bodies of a slow conducting nature may be applied often with advantage to confine heat: such are cork and other woods, light and porous bricks, and stones; among the latter tufa,* and other spongy

* Tufa was used for filling in between the ribs of groined vaults by the Gothic builders. It was formerly quarried and used for building in several places in Derbyshire and Gloucestershire. See Farey's Derbyshire Reports, Vol. I. and Rudge's Gloucestershire.

stalactitical concretions, and pumice-stone* are very slow conductors. But when any of these bodies are used to confine heat in the external air, they should be protected by a coating of matter which is impervious to damp. By some people, brick has been extolled as the best material for houses, because it is a slow conductor of heat; but, it takes in so much moisture in damp and rainy weather, that it is no wonder that scarcely a brick building is free from dry rot. The truth is, bricks should be employed only where they can be protected from moisture; for so powerful is their force of affinity for water, that they will draw it from three to five feet upwards, in a wall standing on a wet base.†

Confined fluids are slow conductors of heat; and gaseous fluids the slowest; and their conducting powers are much diminished by a decrease of density. On a more or less perfect knowledge of these properties, Alberti made walls hollow;‡ Count

* Mr. Gill has lately applied pumice-stone with great advantage in the construction of table furnaces; its slow conducting power was known to Alberti. (Book X. chap. xiii.)

† See my Elementary Principles of Carpentry, Sect. X. art. 339. where the methods of preventing damp are shewn.

‡ Alberti, who is one of the oldest Italian writers on Architecture, writes so much to the purpose on this subject, that an extract will not be unacceptable to the reader. "We may add roof to roof, and wall to wall, and the greater space that is left between these, the cooler will be our shade and the more impenetrable to the heat; for this interval between has almost the same effect for this purpose as a wall of the same thickness would have; and in one respect it is better, because a wall would retain either the heat of the sun, or the cold that had penetrated it much longer, whereas

Rumford put double covers to boilers; and Mr. Watt put jackets to the cylinders of steam engines.* The relative conducting powers of fluids may be nearly expressed as under.†

Mercury	2	— Thomson.
Linseed oil	1·111	— Thomson.
Water	1	
Common air	0·25	— Rumford.

Double windows have been very commonly employed to prevent loss of heat; and the same thing may more easily be done by putting double glass in the same sash, so that the two panes of glass may be about half an inch or more apart, and the inner one not so tightly fitted as to cause it to be strained by the expansion of heated air between the panes.

Several folds of dry woollen or cotton cloth will confine heat effectually, particularly when of an open texture; but a single covering of either will accelerate the cooling of polished metals, (see art. 115.) Linen is less effective as a non-conductor than either cotton or flannel.

If a steam pipe be simply placed within another pipe of larger diameter, and kept in the middle by slow conductors of heat, it will lose only a small

these *double walls* will preserve an equal temperature of the air. In places where the sun is excessively scorching, a wall built of *pumice-stone* will admit the least heat." Book X. chap. xiii.

* It may be useful to remark, that in the case of a jacket to a steam-engine cylinder, the quantity of condensed water ceases to be a measure of the heat which is lost; but it may easily be judged of by the temperature of the external surface of the jacket.

† Dr. Thomson's System of Chemistry, Vol. I. p. 56.

portion of heat; and in many instances a current of air may be drawn through between the pipes, so as to be useful in ventilation, or in supplying fresh warm air; and when this can be done, there will be scarcely any loss of heat. To succeed in obtaining a current, there must be a considerable difference of level between where the cold air enters, and where the warm air is let out.

In conveying a steam pipe to a considerable distance under the ground, in a dry soil, a drain may be formed, and filled at the bottom with brick bats, small stones, or the like open materials; and the pipe laid in so as to be surrounded on every side with about three inches in thickness of dry ashes, covered with a coat of well mixed clay over the top, to keep off the water, and also with such a depth of earth as may be necessary to prevent the pipe being disturbed.

CHAPTER VII.

OF WARMING AND VENTILATING DWELLING HOUSES, CHURCHES, COURTS OF JUSTICE, SCHOOLS, THEATRES, COTTON MILLS, WORK ROOMS, &c.

———" What avail the largest gifts of Heaven,
When drooping health and spirits go amiss?
How tasteless then whatever can be given!
Health is the vital principle of bliss."

THOMSON.

135. The preceding chapters contain the general principles of proportioning and constructing steam apparatus; and the still more essential conditions which will procure good ventilation; it therefore only remains now to give examples of their practical application, so as to join comfort and health with economy. I shall point out such methods as seem to be best adapted for the cases I consider, and limited to the temperature which appears suitable for the particular cases; there will then be no difficulty in making any change, when a different view of the subject renders a change of proportions necessary.

Rooms, Passages, &c. of Dwelling Houses.

In dwelling houses it does not appear to be desirable to employ steam heat alone; but it may

always, in large houses, be made an auxiliary mode of procuring warmth and assisting ventilation.

A large room is seldom comfortably warmed by open fires; and halls, staircases, and passages cannot be warmed by them without a great waste of fuel. But the most advantageous method seems to be, to unite the two principles of warming; that is, in the rooms to use the radiant heat of an open fire, and also supply the rooms with air partially warmed; while the passages, halls, and staircases, are warmed by proper steam vessels. Warming the air which is actually in those places, is better than throwing in warm air; for less fuel is required, and better ventilation is effected by warming the air; and it is much to be preferred to the plan of drawing air from the basement or areas of a house by warming it, for such air is too frequently stagnant, and unfit to be introduced into a dwelling room. Whenever warmed air is to be introduced, it should be brought from a higher level, where it is more frequently changed by winds; and those who know the principles of hydrodynamics will know that there is no difficulty in obtaining this kind of pure air.

We cannot admit of common steam pipes for houses; and it is not necessary that it should be done, for various means may be had recourse to for rendering the steam vessels ornamental. It may be done by giving the vessels themselves an agreeable form, and a character suited to the place; or the common pipes may be collected in masses and covered with open screen work; or with marble or other pedestals; side tables, &c. (Plate III. fig. 12.)

with open-work pannels; or the pipes may be concealed in the walls, and the air be admitted by registers. All that is necessary to be attended to is, that the air may have free access to the heated surfaces, and favourable egress when it has acquired the proper degree of warmth.

When a sufficient quantity of heat is given to the passages, halls, staircases, and galleries, to maintain them at a temperature not exceeding 56 degrees, more warm air will not be required in the rooms than will be diffused from the passages, &c. except there be some of very considerable magnitude, and these might be warmed by pipes covered with open-work pedestals, &c. within the rooms.

Where it is proposed to warm a supply of fresh air for an apartment, the air should not be warmed beyond 56 degrees, and should be admitted at an opening not more than a foot from the floor. The reader who has considered the chapter on ventilation, (Chap. IV.) will perceive the object of these limitations. Dwelling rooms which are used only for short periods, and thoroughly ventilated by the windows between those periods, require less attention to systematic ventilation; yet it is well to provide for a continual change of air in every other case. And in rooms which have not open fires, this continued ventilation ought to be from the ceiling. The same ornament which encircles the lamp hook, may cover the place for the escape of impure air. See art. 62 and 75.

136. In order to give the reader some idea of the

manner of estimating the quantity of heat a given space requires, an example will be best. Let us suppose that there is a hall, a staircase, and two passages, to be sustained at 56° when the external air is at zero; that the hall has two windows, each 10 feet by 4 feet, and that the entrance door to the hall does not open directly to the external air. Let the staircase be supposed to be lighted by a domical skylight 8 feet in diameter, with lapped glass, and 30 feet from the floor, and that there are two windows to each of the passages, each 7 feet by 3 feet 6 inches.

The area of glass will be,

Hall,	80 feet
Staircase,	100
Passages,	98
	278 superficial feet of glass:

and this quantity of surface of glass, by art. 67, will cool 417 cubic feet of air per minute.*

We have next to estimate the quantity of heated air that will escape at the skylight, and other openings of the windows, &c. in the upper passages: all of which will be found fully equivalent to an opening of half a square foot at the skylight, and the air will escape with a velocity due to the height of a column

* In all cases, the quantity of heat required will be greater as the quantity of glass is greater; but from motives of economy let us never exclude the invigorating influence of an abundant supply of light, particularly in schools and workrooms; for the more we exclude light and air, the more pale and languid we shall render the persons who inhabit them. By making the windows double, the loss of heat may be reduced to less than one-third, without sensibly lessening the quantity of light.

of rarefied air 30 feet in height: consequently, the difference of temperature being 56°, we find by the rule, art. 64, note, that $\frac{100\sqrt{30}}{2} = 275$ cubic feet of air will escape in one minute. And, therefore, we shall have to heat 417 + 275 = 692 cubic feet of air per minute, to supply the loss of heat; without estimating any thing for loss by opening and shutting of doors, &c.

Now, by the rule, article 44, we find, that $\frac{692 \times 56}{2 \cdot 1 \times (200 - 56)} = 128$ feet of surface of steam-pipe will be required to produce this effect; which may be grouped in the most convenient places on the ground floor; observing that we have supposed all these places to be open into one another, with the doors seldom closed so as to prevent free communication of air; and in this case, a small quantity of surface of pipe should be appropriated to the staircase, because all the heated air from the other places will flow to it in consequence of its height.

I have chosen this case, which is a very common one, to shew the disadvantage of an open skylight in such a place as a staircase, whenever it is kept at a higher temperature than the outer air.* It is, however, favourable to summer ventilation: and all that is necessary to render it less objectionable in winter, is the addition of a horizontal light that will fit tolerably close, so as to make it a double skylight. An addition of this kind, in such a case as we have

* The heated air is driven out at the apertures of such a skylight by the force of a column of rarefied air, 30 feet high.

here calculated, would save about one-third of the quantity of fuel, and much of the expense of the apparatus for heating the space, and render the house a great deal more comfortable in the winter season.

Churches, Chapels, &c.

137. Churches and chapels are usually lofty and capacious, so that in winter, when heat is required, only a small quantity of ventilation is necessary, on account of the short period the congregations remain in them at one time. But an abundant summer ventilation must be provided for; I shall first consider the means of heating them in winter, and afterwards the ventilation for summer.

Let us suppose a church for 1200 people, to contain 100,000 feet of space, and that the congregation in winter is, at an average, 600, and that there are 28 windows with 1000 feet of surface of glass, and that it is to be kept at 60°, when the external air is at 30°, or 30° above the external air.

Here, by the rule, art. 68, the loss of heat from the glass will be	1500 cubic feet.
Ventilation for 600 people	2400 — —
And the escape of heated air from the windows about	300 — —
Making the total quantity to be heated per minute	4200 cubic feet.

The quantity of surface of steam-pipe that will produce this effect is 428 feet, (see art. 44.) And,

since there is 100,000 cubic feet of space in the church, divide 100,000 by the quantity to be warmed per minute, or 4200, and the quotient 24 is the number of minutes the boiler should be in full action in this case to warm the whole of the air in the church.

In order to distribute the heat, simple steam-pipes of cast iron of about 4 inches diameter, will be found most convenient and effectual. These must be placed according to circumstances; they should not be raised much above the floor, and in most cases will pass conveniently under the seats.

If four-inch pipe be used, you will require as many feet in length as you want feet of surface of pipe, because a four-inch pipe girts very little more than a foot; and accordingly, the boiler should contain 37 cubic feet of steam, for this will be found to be the quantity that would fill the whole of the pipes. (Table IV. art. 219.) See Plate VII.

138. The summer ventilation of a church or a chapel, is an important subject, were it only in so far as bodily inconvenience renders the mind unfit for the duties of the place; hence, the currents of cold air to which a person of delicate constitution is exposed by an ill conducted system of ventilation, should be carefully avoided; for it is a hard case indeed, that such a person should have to encounter, unnecessarily, all the evils of disease, in consequence of attending the public worship of our Creator; I will, therefore, with sedulous attention, endeavour to point out the causes, and the means of lessening the effects of bad ventilation.

When the air of a church is warmer than the external air, if a window be partially opened at some height from the floor on one side of the church, and another be opened on the opposite side, a current will take place; and the colder air from the shaded side will be projected with considerable velocity upon the heads of those seated at some distance from the wall where it enters. If you form the aperture so as to direct the current upwards where it enters, you lessen its effect in a slight degree, because you disperse it more; but still it must descend, though with less velocity, on the heads of those beneath. Small openings to admit the cold air, will only serve to increase its velocity, and consequently, to render it more dangerous; particularly where openings, from which the warm air is emitted, are large, and the vertical distance between the floor and the place of emission is considerable.

To remedy these inconveniences, the spaces for admitting cold air should be abundantly large, and divided as much as possible; they should be near the floor, so that the air may not have to descend upon any one; by making the openings large, and covering them on the inside with rather close wire-work, most of the current may be prevented;* and it may be still further prevented by bringing tubes under the paving, to admit cold air in the central parts of the church. Of course, all such openings must be provided with close shutters.

* Wire-work, with 64 apertures in a square inch, answers very well.

The warm air should escape at the ceiling at different places, through air trunks, furnished with registers, as shewn by fig. to art. 75. The air trunks should be of equal height and equal exposure to the sun. If the apertures be made through the ceiling into the space in the roof, and from this space, an air tube be taken up within the steeple or bell-turret, an effectual ventilation may be obtained without adding outlets to the roof. Where external appearance is less studied, a common luffer-boarded top for an outlet from the roof will answer. All side or end windows should be kept shut, for if the apertures at the ceiling be of proper size, side openings will diminish instead of increase the ventilation.*

Ventilation is most difficult to maintain in close, still, and gloomy weather. Suppose we wish to provide ventilation sufficient to prevent the internal air from being of a higher temperature than 5° above that of the external air; now, if the external air be at 70°, we shall not be able to keep the internal temperature down to 75°, with a less escape of air than 2½ cubic feet per minute for each person, be-

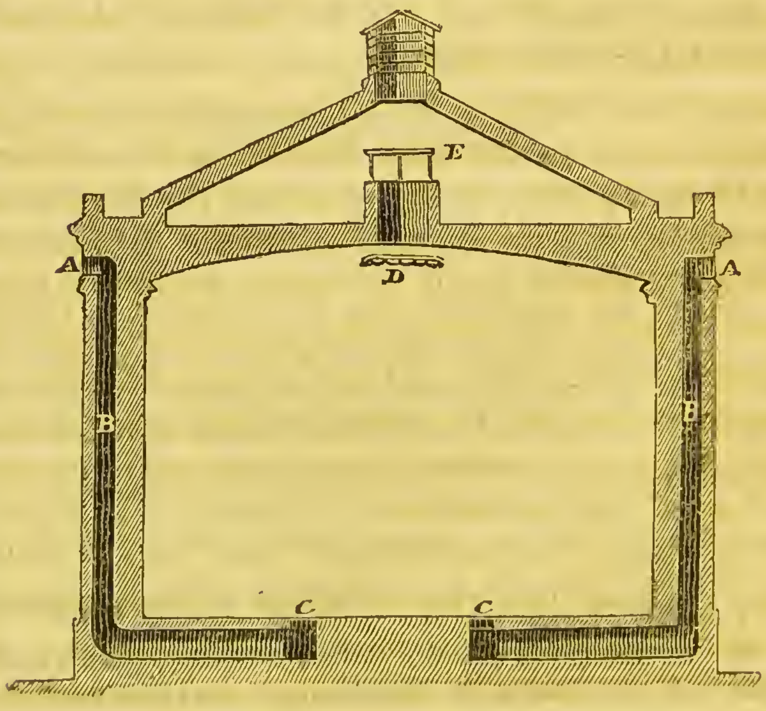
* Since this treatise was ready for the press, a little work on Warming and Ventilating Meeting Houses, was put into my hands, where a method of ventilation, in a great measure similar to the one here proposed is described, and it was found to answer the purpose in every respect; I have, therefore, less claim to originality in the manner of admitting cool air for churches than I supposed. The little work to which I allude is, "Observations on the Construction and Fitting up of Meeting Houses, &c. by William Alexander. Thin 4to. York, 1820." And it contains much that will be useful to a student in Practical Architecture.

cause each person will heat quite that quantity of air 5° in a minute at these temperatures.*

When a church contains 1000 persons, and the height from the floor to the top of the tube is 49 feet, we have to find the sum of the upper apertures, that will allow 2500 cubic feet of air per minute to escape when the excess of temperature is 5°, which is easily calculated by the rule in the note to art. 64. That is $\frac{2500}{30\sqrt{49}} = 12$ square feet. If the height be only 36 feet, then $\frac{2000}{30\sqrt{36}} = 14$ square feet nearly. When the ceiling is level, this area should be divided among five or more ventilators disposed in different parts of the ceiling; but in a vaulted or arched roof, perhaps three will be better, placed in the highest part of the ceiling, as at D in the figure on the next page.

* In art. 56, it is estimated that the quantity of air passing through the lungs in a minute is 800 cubic inches, or say half a cubic foot per minute, and this air is raised to a temperature of about 95°. Now, let t' be the temperature of the external air, and t the temperature the room is not to exceed, and $\overline{x-\frac{1}{2}}$ the bulk of external air that would cool down the air expired, to the same temperature as the room. Then, $\overline{\frac{1}{2}\times 95} + \overline{x-\frac{1}{2}}\,t' = t\,x$, by the the common formula for ascertaining the temperature of mixed portions of the same fluid. (Playfair's Outlines of Nat. Phil. art. 317, Vol. I.) Hence, $\frac{95-t'}{2\,(t-t')} = x =$ the cubic feet of air to be removed by ventilation per minute, which, in the case in the text, is $\frac{95-70}{2\,(75-70)} = 2{\cdot}5$ cubic feet. This must be the least quantity, because a considerable quantity of heat is given off by the surface of the body, the amount of which has not been ascertained.

The openings for admitting cold air should be about double the area of those at the ceiling. The air should not be taken from very near the ground, nor from a confined place. In a new building it might be prepared with flues for cold air down the piers between the windows, for the air to enter at A in the frize under the cornice, pass down a smooth flue, and rise into the church through gratings in the floor, C C; and by disposing some of these flues on each side of the church, they would act with the wind in any direction. The flues for admitting cold air may have their entrances A, A, at any lower points; and it is not necessary they should be in the walls; indeed, the same effect may be obtained in various ways, which will readily suggest themselves,



according to the circumstances of the case it is to be applied to.

Schools, Lecture Rooms, Libraries, &c.

139. The same principles apply to schools, lecture rooms, &c., as to churches, when steam heat is employed; and the same principles of ventilation, whatever mode of applying heat be adopted; therefore, they need not be again reduced to examples. But in small schools, &c., on the ground floor, stoves may be used with more advantage, are less expensive, and require less attention. The mode of applying a stove to give an uniform heat to such a school, is nearly the same as that employed for warming green-houses, viz. the flues are conducted in a conduit under the floor, with gratings to let the warmed air into the room. The fire-place should be formed nearly in the same manner as for a boiler, see Plate II.; only, in the place of the boiler, the flue should be covered with a double thickness of Welsh fire-tiles of about 18 inches square, with the joints crossed to prevent the escape of smoke or vapour from the fuel. At the distance of about 10 feet from the fire, the smoke should enter an iron pipe, of about 9 inches diameter, and about 30 feet in length for an ordinary chimney, but shorter where there is a bad draught, and longer where there is a good one, the end of the pipe terminating at the chimney. The pipe of cast iron may be formed of the common water-pipes, and put together

in the same manner, and supported on rollers so that the joints may not be opened by expansion; the loose end should be that in the chimney; and make the same allowance for expansion as for steam-pipes, that is 1-8th of an inch for every 10 feet in length, though it will rarely exceed half the quantity. The conduit under the floor, which is to contain this pipe, should be large enough for the pipe to be 3 inches distant from the bottom and sides; and it should be dry and plastered smooth in the inside. The cold air to supply the ventilation, is to be admitted into this conduit at some point near to the fire; and in the paving of the floor there are to be gratings for letting the warm air into the room, and also to allow that which has been cooled to descend into the conduit to be heated by the pipe.*

A stove constructed in this manner, will soon afford heat after the fire is lighted; it is of some advantage to put a damper in the chimney to regulate the draught. When the distance between the fire and the chimney cannot be brought within the limits before specified, the iron flue may be made of smaller diameter. And in other cases it will be necessary to return the flue, as when the fire-place and chimney are together.

The size of the fire must be regulated by the heat required, which will be ascertained by art. 68;

* Instead of using pipe for the flue I have sometimes made the sides of fire-brick, and the bottom and top of cast-iron plates with a rebated joint; this mode of construction is more easily managed in practice, and affords the same effect.

from which the cubic feet of air to be warmed per minute will be found; and to keep the temperature at 60° when the external air is below freezing, the pounds of coal to be consumed in an hour, will be ascertained by multiplying the cubic feet of air to be warmed per minute by 0·00472.* The size of the fire to burn a given quantity of coal is shewn in art. 97.

Theatres, Opera-Houses, &c.

140. In applying heat to theatres and places of a like nature, steam will always be found most safe and economical. The proper ventilation is of considerable importance, and may be easily effected on the same principles as have been explained for churches. But it may be useful to remark, that Mr. George Saunders, who studied every means to avoid the loss of sound, says, "the apertures necessary for changing the air, should have covers to fit close, and be opened only between the acts;"† considering, and very justly, that much motion in the central parts of a theatre, would increase the difficulty of hearing. To avoid this difficulty the air which collects in the upper part of the boxes, might be easily conveyed by separate tubes to the upper

* For 0·00000262lbs. of coal will heat one cubic foot of air one degree, (art. 23,) and if A be the quantity of air to be warmed per minute, 60 A will be that for an hour, and it is to be warmed 30 degrees; therefore, $60 \times 30 \times A \times 0{\cdot}00000262 = 0{\cdot}00472$ A.

† Treatise on Theatres, p. 32, 4to. 1790.

part of the house, and escape by the ventilators at the top. This mode would reduce the motion of the air in the central parts of the house; and consequently, render continued ventilation less objectionable, besides giving the advantage of good ventilation at the back part of the boxes, where it is most required. The same writer remarks that the apertures for admitting fresh air should be general, that is, distributed over every part of the house, to prevent the occurrence of draughts of cold air; a plan which perfectly coincides with my own ideas on the subject: and in the winter season it would be desirable to warm the fresh air as it is admitted. In summer, we should be able to keep the temperature down to within 5° of the external air in sultry weather, and suppose the air to be at 70°, then, an area for $2\frac{1}{2}$ cubic feet per minute to pass through, should be allowed for each auditor (see art. 138 note); and, as the height of a theatre is from 40 to 50 feet, from the pit to the ceiling, and there is at least the height of the roof in addition, we may take 64 feet for the height of the column of rarefied air: and by art. 64, (note) we have $\frac{2\cdot5}{30\sqrt{64}} = \frac{1}{96}$ of a square foot for each auditor. That is, in a theatre for 2000 people, there should be $\frac{2000}{96} = 21$ square feet of ventilators. Considering the motley character of the audience of a public theatre, I have no doubt that some of my readers will think I have allowed less than is desirable; in answer, I say, the stay in a place of this kind is short; it is in the rooms

we most frequently inhabit where ventilation is most necessary.

Cotton Mills, Silk Mills, &c.

141. The first attempt to heat cotton mills by steam, appears to have been made by Mr. Neil Snodgrass, in 1799,* and it has since been very generally adopted. It is found greatly superior to other methods, and a more salubrious mode of obtaining the high temperature which these mills require. Until the machinery acquires a certain degree of warmth, the spinners find it nearly impossible to keep their work in order; and this is most felt on Monday mornings, when every thing has become more cold and adhesive, through being a longer time at rest. It is an evil, because, in addition to producing bad work, it too frequently occasions the children employed to be treated with unmerited severity; than which nothing has a greater effect in debasing the sense of justice and honesty in a young mind. In cotton mills ventilation is very sparingly introduced, whereas it ought to be most abundant in a place kept at an elevated temperature. The additional quantity of fuel this degree of ventilation requires cannot be withheld by any person endued with either honesty or humanity. Pure and wholesome air is as necessary to the well-being of man, as pure and wholesome food; and he that would knowingly compel his

* Transactions of Society of Arts, Vol. XXIV. p. 199.

work people to live in an impure atmosphere, is equally as criminal as the adulterator of bread. But I must proceed to shew how warmth and ventilation may be conducted with advantage; and perhaps these lines may meet the eye of a second HOWARD, who will see that something equivalent to them is put in practice, by the few who neglect to attend to the good of the people they employ.

The heat for a cotton mill may be taken at 70 degrees, when the external air is at 30°. Let us suppose the mill to be 5 stories in height; 60 feet in length, 33 feet in breadth, the number of doors and windows 70, and the area of the glass of the windows 1,000 feet. Let there also be ventilation for 200 people, then by art. 68 there should be $770+800+1{,}500=3{,}070$ cubic feet of air, heated from the temperature of the external air to that of the mill in a minute. And by the rule art. 44;

$\frac{3070\times 40}{2\cdot 1\,(200-70)}=450$ feet of surface of cast iron steam-pipe, would sustain it at 70, with the external air at 30°; part of this quantity to be in air chambers, and the other in the work rooms as described below. For, the most convenient plan for ventilation will be to partially warm the fresh air before it be admitted; it will render a less quantity of steam pipe necessary in the work rooms, and keep them at a more equal temperature. The windows should be rendered as close as possible, and outlets for the impure air provided at the ceiling, with registers to regulate them. The fresh air would be best introduced at various parts in the floors, or near

to them, and when it is managed in this manner, the air will be apparently still; the light dust will be borne away by the ascending air, and also the vapour; the rooms will be drier, and the air purer. In a new building the cast-iron pillars which support the floors may be made hollow, and to answer the purpose of air tubes. In other cases air pipes of tinned iron, or sheet zinc, or earthen* tubes, may be employed for distributing fresh air, placed within the building that no heat may be lost. A small chamber to contain three or four returns of steam-pipe, should be made as described in the figure to art. 144. to receive the fresh air at the lowest point; at the bottom of this chamber the cold air should enter, and being heated by the pipes, would ascend through the air pipes into the rooms. When different stories are to be warmed by the same apparatus, the air chamber must be divided into compartments, one for each story; and registers to regulate the admission of warm air will be necessary.

The dimensions of air tube for one story will be easily found in this manner; it will be required largest when the external air is nearly of the same temperature as the mill. Let the height from the floor of the air chamber to the ceiling of the story be 30 feet, and the number of individuals at work in the story 40; and the air be warmed 10 degrees above the temperature of the external air before it enters, when the air of the room is 20 degrees above.

* The interior of the earthen tubes should be glazed, in order that the air may accumulate no dust in its passage through them.

Then, by art. 61, we have to admit $40 \times 4 = 160$ cubic feet of air per minute; and by art. 64, note, $\frac{160}{43\sqrt{30}} = 0{\cdot}7$ feet, or about 100 square inches for the area of the pipes for air; and the pipes to conduct away the impure air and vapour from the ceiling need not have more than two-thirds of this area. The quantity of steam-pipe for the air chamber, should be sufficient to heat 160 cubic feet of air per minute 30 degrees, when the external air is 30°; but the air will first come in contact with the pipes at 30°, and ought to quit them at 60°; therefore we may take the mean or 45° to calculate the effect of the pipes; and by art. 44, $\frac{160 \times 30}{2{\cdot}1\,(200-45)}$ $= 15$ feet nearly, for the surface of steam-pipe in the air chamber, for one story situated 20 feet above it. The air chamber should be formed on the principle exhibited in the figure to art. 144. The reason for admitting the warm air at a lower temperature than the rooms are to be sustained at is obvious; for it would rise immediately to the ceiling, and escape instead of the impure air, if it were to enter at the same temperature; and therefore the ventilation would be retarded instead of being improved.

The steam-pipes in the rooms will give the rest of the heat required, and may be arranged in that manner which is thought most convenient, provided they are near the floors. If proper care were taken to close all the side apertures that admit cold air, the expenditure of fuel would not exceed that

on the old plan, where there is scarcely any ventilation.

If the condensed water cannot be returned to the boiler, it would be an advantage to let it collect in the pipes, even where a steam engine is supplied from the same boiler; because less time would be consumed in raising the temperature in the mornings; or the steam might be turned off an hour or so earlier at nights, the rest of the time being supplied by the heat of the water in the pipes. The person attending the boiler fire will have to let off the water every morning when he lights the fire.

Plate VIII shews how steam has been applied to warm a silk-mill at Watford.

Musical Instrument Makers', Cabinet Makers', &c. &c. Work Rooms.

142. In the manufacture of various articles made of wood, it is desirable that the work rooms should be dry, and sustained at a moderate heat in winter, equal to that of dwelling rooms; otherwise the articles are of an inferior quality, if not wholly unfit for the purpose they are intended for. It is not, however, very good either for the health of the workmen, or for the articles constructed, that the temperature should be greater than it is usually found in common dwelling rooms; that is, about 60 degrees. An example will best explain the mode of obtaining this degree of heat by means of steam; which is certainly the safest method of heat-

ing such places, besides having some advantages in heating glue, drying wood, and laying veneers, which cannot be easily obtained by any other method.

Suppose a work room to be 50 feet by 20, with windows on one side, in a continued range, the whole area of the windows being 250 feet; and the loss of heat from the windows (by art. 67) will be $1{\cdot}5 \times 250 = 375$ cubic feet per minute. If twelve workmen be employed in the room, then the loss of heat from proper ventilation, (by art. 61) will be about 48 cubic feet per minute; and the whole quantity of air to be heated per minute, will be 423 cubic feet. The quantity of surface of steam vessel that will heat this quantity, when the external air is at 30°, calculated by the rule (art. 44) $\frac{423 \times 30}{2{\cdot}1 \times (200 - 60)} = 43$ feet; consequently a single four-inch steam pipe continued along the length of the room will be sufficient. The pipe may be continued along the window side, beneath the windows, and a small plate may be fixed at each work bench to place a glue pot upon for the use of the workmen. Also, where it is required, a shallow box with a flat top of cast iron may be fixed in a convenient place, for heating veneers, and the grounds on which they are intended to be laid.

The whole of the pipes without the box, it will be found, will contain about 5 cubic feet of steam, hence there should be space for this quantity in the boiler; and about 4 cubic feet of water will be

evaporated in twelve hours, which will require about half a bushel of coals per day; or an equivalent quantity of coke, or of the refuse of the workshop. But there will be heat lost at the boiler; this should be made use of in drying materials. (See Chap. XI.)

Steam has been successfully applied to heating copperplates, and warming the work rooms for copperplate printers, by Mr. J. Ramshaw.* Before steam was applied the plates were warmed by charcoal stoves, which were injurious to the health of the workmen.

* A description of Mr. Ramshaw's apparatus is given in the Transactions of the Society of Arts, Vol. XXXVI. p. 95.

CHAPTER VIII.

OF WARMING AND VENTILATING HOSPITALS, INFIRMARIES, FEVER-HOUSES, HOUSES OF EQUAL TEMPERATURE, PRISONS, &c.

> Are we from noisome damps of pest-house free?
> And drink our souls the sweet ethereal air?
>
> THOMSON.

Hospitals.

142. In all places devoted to the relief of the sick and the infirm, crowding many people together without due attention to ventilation, may generate a greater portion of misery than there is the power to relieve. It has not unfrequently happened, that diseases have assumed a more obstinate nature, and sores a more malignant character, in hospitals where great attention has not been given to purify the air, and to remove noxious effluvia.* On the other hand, it is equally true, that the institution of health offices, hospitals, and fever-houses, have been the means of checking the progress of infectious diseases, and preserving the health of populous districts, where the ravages of such diseases are most dreadful.

The choice, where there is the latitude of choice,

* See Howard's Account of the Lazarettos of Europe, pp. 11, 54, 56, 60, &c.

of an open and healthy situation for buildings of this kind, is of great importance; it has been said that architects seldom aim at more than perfection of exterior proportion:* but the truth is, architects are seldom consulted on this point; for if the writers on architecture be studied, it will be found that they have not overlooked the effect of the situations of buildings on health;† but it would extend this work too much to treat of the subject here.

In providing a suitable degree of warmth and ventilation for an hospital, it will always be desirable that these operations should be as distinct as possible; they ought both to be perfectly under the command of the attendants, and the ventilation so conducted that there may be no injurious currents of cold air; that it may be equally effectual in dispersing the heavy polluted air, and the lighter gases, vapour, and effluvia; that the ventilation may be abundant, without producing much agitation in the air, and that there may be the means of pro-

* Philosophy of Domestic Economy, p. 2.

† See Vitruvius, lib. I. cap. ii. iv. and v.; also lib. VI. cap. vii.; and Alberti introduces the subject by saying, "The ancients used the utmost caution to fix upon a place that had nothing noxious about it; and especially, they took particular care that the air was not unwholesome or intemperate; for they knew, that if the earth or water had any defect in them, art and industry might correct it, but they affirmed that neither contrivance nor multitude of hands was sufficient to correct or amend the air. And it must be allowed, that, as what we breathe is so conducive to the nourishment and support of life, the purer it is the more it must preserve our health." Book I. chap. iii. iv. and v.

ducing a more rapid change of air to purify the rooms when necessary.

Though I have not here to consider the nature of the construction of a building proper for an hospital, it may be useful to remind the reader, that every species of matter that absorbs effluvia, every thing which becomes damp and adhesive in a moist atmosphere, should be used as sparingly as possible in the interior of an hospital. The effect of all such substances in collecting deleterious matters is incredible; and after they have absorbed a quantity, mere ventilation will be found ineffectual in removing it.* We must either have recourse to exposing those substances to the joint action of the sun and air, or remove it by washing with water, or by the diffusion of a volatile acid. (See art. 74, and note.) As far as my own observations have extended, all painted surfaces soon attract a considerable quantity; and particularly when the paint is upon metal. In fact, unless metal could be kept with a clean polished surface, (which is impossible,) it is not so good as close-grained wood, because the air condenses on the metallic surface at every change of temperature. For bedsteads and other moveables, smooth compact wood should be used; their forms should be simple, so that every part may be easily cleaned, and their surfaces saturated with oil instead of being painted with body paints. There should be no more linen,

* "The leaves of my memorandum book," says Howard, "were often so tainted, that I could not use it till after spreading it an hour or two before the fire." Howard on Prisons, p. 13.

cotton, or woollen matters than comfort and decency render necessary; but when these are frequently changed, and part of the drying done in the open air, in a place where they can have the effect of the sun, the use of these comforts should rather be regulated by the expense than by any danger of creating a source of impurity. For the very circumstance of their free absorption of effluvia must rather tend to improve the place than otherwise, provided they are frequently changed, and thoroughly cleansed at each change; the same remark will apply to every other moveable that can be easily taken out. It appears to me, that a room, with a south aspect and free ventilation, would be a desirable addition to each floor of an hospital, for the purpose of wheeling all the bedsteads into that are not occupied during the day, whenever the weather might be fine and clear. The walls and ceilings of the wards and passages should be well plastered, so as to be smooth and even; and only lime-whited, with lime slacked in hot water, and the addition of a small portion of colouring matter to take off the glare of so much white.* Where the walls are likely to be rubbed against, the lime may be mixed with beer grounds, but not in other parts; and size-colouring should not be used.

In constructing the parts necessary for ventilation,

* The use of hot lime in destroying infectious effluvia, is admirably illustrated by Howard's experiments on the rooms in which he was placed at Venice, when he arrived there in a vessel which was suspected to be infected with the plague. Lazarettos of Europe, p. 11 and 119.

the tubes for air to go out at should be plastered where they are sufficiently large, and smaller ones constructed of either earthenware or wood; while the tubes for admitting fresh air may be made, with advantage, of metal. Sheet zinc would answer very well for the latter, or tinned iron.

When the air is to be warmed as it enters, the process will not go on when particular winds prevail, unless it be admitted at some point on the windward side of the building, or by a high air-flue, with a top that is formed so that the wind may force the air down it, in whatever direction it blows. If all these circumstances be not attended to, the best constructed apparatus will be ineffectual with some winds.

143. These preliminary remarks will perhaps be sufficient to render an example intelligible; and if we take the case of a single ward, the whole of an extensive hospital will be only the repetition of the same calculations, with the necessary variation of heights, &c.

Let us suppose a ward to be 90 feet in length, and 22 feet wide, the height 10 feet, and to contain 30 beds, or 30 people and attendants, the surface of 15 glass windows being 400 feet. Hence, (by art. 68 and 73,) $(6 \times 38) + (11 \times 15) + (1 \cdot 5 \times 400) = 993$ cubic feet of air to be heated per minute; hence, we may calculate on 1000 feet. Now, as the ventilation should be continued through the night, there should be this quantity warmed constantly. The temperature in the night may some-

times be at zero; and if, in that case, the air be kept at 50° in the ward, it will be sufficient, and (by art. 44,) $\frac{1000 \times 50}{2 \cdot 1\,(200-50)} = 160$ feet of surface of steam-pipe. But the portion to supply the ventilation should be warmed to about 40° before it enters; in this case, therefore, the quantity $38 \times 6 = 228$ cubic feet should have this degree of heat communicated to it in a small air-chamber, as shewn in art. 144, which will require $\frac{228 \times 40}{2 \cdot 1\,(200-40)} = 27$ feet of surface of steam-pipe; hence, the quantity of steam-pipe for to be in the ward is $160 - 27 = 133$ superficial feet. In disposing this pipe, I should prefer continuing a small pipe along the wall on each side of the ward, at about 3 inches from the wall, and 5 or 6 inches from the floor. This will render it necessary to prevent the bedsteads going close to the wall; but such an arrangement will allow a free course of air round them, and be rather an advantage.

The pipes in an hospital should be arranged so that the steam may pass in a small pipe direct from the boiler to the highest level; a gentle descent being given to the steam-pipes from that point till they terminate in a small pipe, which should convey the water of condensation to the boiler.*

The passages should be warmed nearly to the same temperature as the wards; and the best plan of ventilating them appears to be by introducing

* The proportions of these pipes will be found by art. 127 and 130.

warm air at such a temperature as will assist to expel the colder part through the water closets, as described in art. 79. If we pursue any other mode of ventilation, it will have a tendency at all times to interfere with the more important processes of ventilating the wards and the closets. For the greater height of a column of rarefied air in the stair-cases will overpower the ventilation in the wards; and drawing the vapour, impure air, &c. out of them, it will, in its slow ascent in these wide spaces, be cooled to the density of the atmosphere, and we shall have them filled with a heavy mass of impurities, as too frequently is the case at present.

In order to give effect to the system here proposed, the doors to the wards should be as low as possible; there should be no processes carried on in the open passages which will injure the air—as they may always be done with equal convenience in places separated from the passages, and with low doorways into them, and a small ventilator at the top of each.

The size of the ventilators for the wards must be regulated by the summer ventilation. Let the height from the floor of the ward to the top of the air-tube be 25 feet. In a note to art. 138 it has been shewn, that an individual will require 2½ cubic feet of fresh air per minute, to prevent the temperature increasing from 70 to 75°, but in this case we shall provide for a change of only 3° of temperature, when the external air is at 71° in the shade, which will require 4 cubic feet of air to escape per minute

for each individual; hence, (by art. 64, note,) $\frac{38 \times 4}{23 \cdot 6 \sqrt{25}} = 1 \cdot 3$ feet square for the sum of the areas of the ventilators for the ward; and it should be divided into several, placed at different parts of the ceiling of the ward. (See art. 75—79.)

Houses of Equal Temperature.

144. The numerous and distressing cases of *consumption* in our climate, and also of many other *pulmonic* diseases, has directed the attention of medical men to the means of procuring for their patients the advantages which are said to be derived from a removal to warmer climates; and if no other benefit should arise out of a scheme of this kind, at least it may prevent many a sufferer being torn from the arms of his friends, to sink a victim to disease in a foreign land: to which he seldom sets out till there is not a shadow of hope remaining. If an institution could be established, by which the effect of a milder climate could be resorted to in the first stages of this disease, without either the expense or the disadvantages which must attend a journey to a foreign country, it would surely be better than the present system. But still better than an institution, it would be, to have an easy means of rendering a common dwelling house capable of fulfilling every essential condition which a place of this kind requires.* For

* The first proposal for such an institution was made by Dr. George Pearson, in an anonymous communication to the Philosophical Magazine, Vol. XXXI. which he afterwards acknowledged

to bring together and mix a great many persons labouring under the same disease, must too often be exceedingly hurtful; and to provide distinct apartments for each would be attended with too much expense to be practicable.

The first object must be to make the room as air-tight as possible, which may be effected by pasting strips of canvas and paper over all the openings; and further, to prevent a sudden influx of cold air, a double door may be added, either within, or on the outside of the room, as may be most convenient, —the additional door being made as small as will answer the purpose. Let the chimney be closed up, and add a sash to the window, so as to render it a double one.

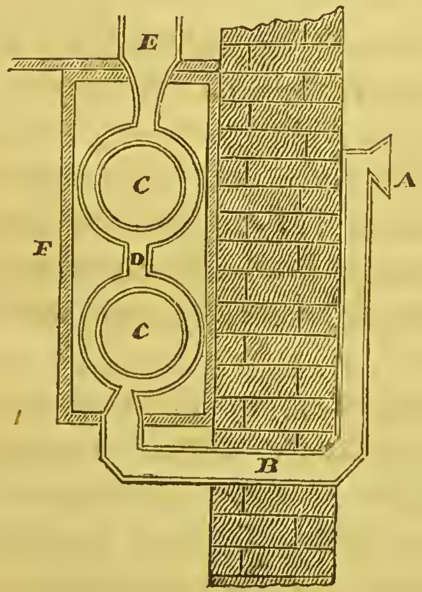
The next object should be, to admit as much warmed air as will ventilate the room, and allow the other to escape at the ceiling. The warm air admitted should be 5 or 6 degrees below the temperature the room is kept at; the rest of the warming to be effected within the room. The quantity of air to be warmed for ventilation, we will suppose to be 12 cubic feet per minute for one room; and the room being kept at 62°, the air should be heated to 56° before it enters.* This may easily be effected

in Vol. XXXIV. of the same work, and further recommended. The proposal of Dr. Pearson called forth a most interesting paper on the subject, which suggested the mode I have adopted in treating it. See Phil. Mag. Vol. XXXV. p. 62.

* Perhaps even a higher temperature may be desirable; as to afford the patient a pure but rarefied atmosphere, seems to be the object which medical men have in view.

by means of a boiler to be kept on the hob of a kitchen fire, or a small portable boiler, of the kind used for steam-baths; with tinned iron pipes to receive the steam, placed so that the condensed water may return to the boiler. The air to be warmed should be brought from the external air as at A, to pass through the wall B, and round the steam tubes C, C, being confined to act upon them by a case of tinned iron, D, D; and the air being warmed, rises through the pipe E into the room. In order to prevent loss of heat, the whole may be inclosed by a wooden case, F.

A pipe of the same size as the pipe A E will be required for the escape of air at the ceiling, and the



size of both these pipes should be such as would afford the proposed degree of ventilation when there would not be more than 10 degrees of difference

between the temperature of the external air and that of the room. Therefore, take the vertical distance between the air chamber D, and the aperture where the air escapes, which, suppose to be 16 feet; and, by art. 64 $\frac{12}{43\sqrt{16}} = \frac{3}{43}$ for the area of the tube in feet; or, $\frac{144 \times 3}{43} = 10$ square inches, or about $3\frac{1}{2}$ inches diameter; and they should each be provided with a register to regulate them.

The quantity of steam-pipe to heat the air chamber to 56°, when the external air is at 30°, will be $\frac{12 \times 26}{2{\cdot}1\,(200-43)} = 1$ foot of surface, if they were of cast iron; but it will require nearly 2 feet of surface of tinned iron to give the same quantity of heat, (see note to art. 42;) hence, the surface of the tubes C C, should be 2 feet, or they may be 4 inches diameter and 1 foot long: the steam to pass in a small pipe from the boiler into the upper tube, and from thence into the lower one, and return when condensed to water, by a small pipe to the boiler.

About 4 feet of surface of cast-iron pipe or vessel, or 8 feet of surface of tinned iron, will supply the heat required in the room, to keep it at 62°. Therefore, when the kind of vessel is determined which will afford this quantity of surface, it should be fixed near to the floor, and so that it can be supplied with steam by a small wrought-iron pipe from the boiler. The condensed steam may return by the same pipe. A stop cock should be placed in the

pipe, so that the supply of steam may be regulated by any person in the room.

A boiler to contain about 3 gallons of water, with an equal space for steam, will be sufficient for this purpose.

These proportions are sufficient for one room, but two will in general be required; the effect may then be produced by doubling the proportions here given, and so of any number, when each room is to accommodate one individual. Large rooms should have the preference for day rooms; for space is very desirable, both to give more cheerfulness and latitude for exercise; when the room is large, about two-thirds more heat must be given.

Prisons, Penitentiaries, &c.

145. In places for confining felons and the like, the chief object is to give good ventilation; for whatever punishment it may be thought proper to inflict on those who have violated the laws of their country, they should be preserved from disease.

"Warming the rooms in any manner is unnecessary," says Howard,* "to those in health; but the sick must be provided for;" and the infirmary of the prison being provided with the means of giving warmth, will be sufficient for the latter object.

Now, with the means of letting out air at the ceiling, and of letting in a fresh supply at the floor,

* Lazarettos of Europe, p. 202.

it is impossible that the ventilation can ever be imperfect, if it be contrived so that winds may not cause an interruption. (See art. 142, towards the end.) On the other hand, when ventilation is attempted by opposite apertures in the sides, it is in windy weather only that ventilation can proceed; and even then not with advantage, as will be evident from the principles established in the fourth chapter. There ought to be the means of regulating the quantity of ventilation according to the season; but, after the examples of conducting the processes which have been given, it will not be necessary to enter into the detail of a subject which receives so much of its character from the nature of the place where it is executed.

CHAPTER IX.

OF HEATING STOVES, FORCING-HOUSES, GREEN-HOUSES, CONSERVATORIES, AND OTHER BUILDINGS FOR PLANTS.

Impatient art rebukes the sun's delay,
And bids December yield the fruits of May.

YOUNG.

146. THE plants which require artificial heat in this country, are generally arranged in catalogues under two classes; that is, greenhouse and stove plants. These plants, the produce of climates differing from ours, can be preserved here only by artificial heat. We have to form a climate suited to their respective habits; but, in order that they may arrive, as nearly as possible, at their native perfection, it will be best to let the periods of extreme heat and cold coincide with those of this climate.

In providing for such plants, convenience of exhibition and neatness of arrangement, at least, should be studied; but often the buildings to receive them are made in the highest degree ornamental; and to my mind the beauties of architecture never appear to greater advantage than when associated with the beauties of nature.

Artificial heat is also employed to accelerate the

period of fructification of plants; and to produce the fruits of warmer climates. To attain these objects it is desirable to economize heat; and only to form such buildings as are convenient for attending to the plants, and adapted to produce the desired end at the least expense.

147. It cannot be here attempted to enter generally into the system of managing plants, but a little inquiry will be useful; as otherwise, we should have an imperfect notion of the quantity of heat necessary for the different kinds of houses; but this inquiry should obviously be restricted to the regulation of temperature;—a gardener's researches should embrace other, and not less important objects.*

The temperature which is most favourable in the natural state, is most likely to agree with the artificial one: the common practice of sustaining a temperature nearly uniform is not the proper method of treating plants; a diurnal season of rest is as necessary to a plant, as to an animal; it cannot be constantly under the same exciting power of heat without injury—as is obvious from the feeble and unhealthy state of stove plants when an equable heat is attempted.†

* It is extremely desirable that there should be more attention paid to the hygrometrical state of the air in hot-houses; but the want of a simple, cheap, and convenient hygrometer, will delay the general introduction of this instrument.

† Bosc says, "the temperature of the stove scarcely varies, and the plants grow without interruption." (Art. Serre. Agricul. Ency.

It has been shewn by vegetable physiologists,* that the leaves of plants do not perform the same functions in the dark as in the light, and that a rise of temperature has a sensible effect on their organs of respiration. If the air be allowed to cool in the night, it will generally deposit a portion of vapour on the plants; if it be kept warm it will tend to exhaust them of moisture. And as the leaves of plants absorb oxygen and moisture in the night, and give out a portion of this oxygen in the day, when exposed to the light of the sun, we may infer that both the exciting causes of the operation of the day functions, that is, light and heat, should be less powerful in the night. A view of the provisions of our All-wise Creator, will tend to confirm this opinion. No where within the limits of vegetation, is the heat equally as powerful in the night as in the day; there is not in any place a perfect regularity of seasons; shall we not, then, succeed the best in treating plants, if we take a lesson from nature, and imitate the changes of temperature which plants experience in the natural

Metho.) Now by sustaining the plants at such a temperature as to keep them constantly growing, they are sure to become exhausted, sickly, and etiolated.

* See Dr. Thomson's System of Chemistry, Vol. IV. p. 352—359. Dr. Murray's Chemistry, IV. p. 40. Saussure, Quarterly Journal of Science, XIII. p. 153. Dr. Gilby, Edinburgh Philosophical Journal, Vol. IV. p. 100; Mr. Knight's Papers in the Transactions of the Horticultural Society, Vol. II. pp. 130 and 224, and Vol. III. p. 459; and Napier's Supp. to Ency. Brit. art. Vegetable Physiology, pp. 728, 787.

state? The experimental researches of Mr. Knight* gave the first public opening to this interesting inquiry; yet it appears to have been for some time studied by Messrs. Loddiges, and made the guide of their practice.

148. There are several other circumstances, besides geographical position, which cause a variation of temperature in different situations: the most important are, the height above the level of the sea, the state of the surface of the country, and the distance from the sea coast, the nature of the soil, the presence or absence of mountains, and the prevailing winds. It also may be remarked, that the climate of islands differs from that of continents. The researches of Baron Humboldt, on the distribution of heat on the surface of the globe,† are the most extensive, and afford the best known data for the mean heat of climates: but this is not the purpose of our inquiry.

Though each plant has, in general, a determinate climate, in which it thrives best; yet one stove may be sufficient to preserve a great variety of plants: but where it is desired that they should arrive at perfection, at least two will be necessary, that is, one for those which require moist heat; and one for those which require dry heat. And in more complete collections, more will be necessary; as the heat of two of these stoves should correspond with the tropical climates, the other

* Transactions of Horticultural Society, Vol. III. p. 459.

† Edinburgh Philosophical Journal, Vol. IV.

with those parts of the temperate zones which join the tropics.

In a stove for plants of the torrid zone, it is desirable to know the mean noon-day heat of the coldest month; and the mean night heat of the same period, at some place within the tropics where it is known to be most favourable to the vegetation of the plants of that zone. It will further be useful to know the mean noon-day heat of the hottest month, and also the mean night heat of the same time, in order to regulate for the summer temperature. The mean temperature of the year is of little use in this inquiry, because our object is to ascertain the change of temperature most conducive to the well-being of plants, and the lowest temperature to which they may be safely exposed; under the impression that the Author of Life would have provided them an uniform heat if it had been either necessary or useful.

149. The quantity of daily range, and the variation of season, appear of more importance to vegetation than the mean temperature; and these may differ greatly, while the mean temperature remains the same: but they have been less observed, and less studied, than their effects on plants would have led one to expect.

Between the tropics, at 10½ degrees N. latitude,*

* From Mr. Caldcleugh's observations, it appears that at Rio de Janeiro, (Lat. 22° 54′ S.) the dew point was never at less than 55° in the middle of the day, during the month of August 1821, and often as high as 62°, indicating more than six grains of water in each cubic foot of air. The thermometer varied from 69 to 79,

the mean heat of the warmest month is 84°; the mean heat of the coldest month is 80°; the extreme heat is about 110°; the extreme cold about 66°; and the mean temperature of the year 81½°.

A house for the plants of the warmer parts of the temperate zones, may be regulated by the temperature of latitude 42°, where the mean heat of the warmest month is 77°, the mean heat of the coldest month 42°, the extreme heat 99·5°; the extreme cold 36·5°; and the mean temperature of the year 60°; mean temperature about 51°, during nine months of the year.*

In the neighbourhood of London, in the warmest half quarter, the mean heat is 63°; the mean mid-day heat is 71°; the night heat 54½°; mean daily range 16½°. In the coldest half quarter, the mean

observed at noon, during the same period. It is the wet season of the year, at that plaee; and the annual mean temperature is 73°. Quarterly Journal of Seienee, Vol. XIV. p. 42; or Daniell's Meteorologieal Essays, p. 338. See also Capt. Edwd. Sabine's observations in the same work, at other plaees between the tropies.

* The observations of Mr. Colebrooke at the Cape, (Lat. 33° 53′ S.) and the eonelusions he has drawn from journals kept there, contain a view of the elimate of southern Afriea, whieh the eultivators of Cape plants will be interested with. The mean annual temperature is 67½°. The extremes 96° and 45°. Mean temperature of the eoldest month 57°, of the warmest month 79°; least heat during summer 63°—the thermometer being kept within a large apartment. (Quarterly Journal of Seienee, Vol. XIV. p. 241.) Other observations made at Graaf Reynet, (Lat. 32° 11′ S.) give the annual mean 62·19°; the extremes 100° and 34°; the mean temperature of the eoldest month 53·79°, mean daily range 22°; of the warmest month 71·3°; mean daily range 21°. (Edin. Phil. Journal, Vol. V. p. 281.)

heat is 35¾°; the mean mid-day heat is 38¼°; the night heat 32¾°; and the mean daily range 6°. The mean heat of the year 48¾°; extreme heat in the shade 89°; extreme heat in the sun 144°; extreme cold 11°; mean dew point 44½.* The mean temperature above 51°, during nearly six months of the year.†

Now the winter season is the time when most heat is necessary, and therefore the pipes being arranged to give the proposed degree of heat at that time, that of any other period will be obtained by regulating the fire. But in winter we may estimate that the thermometer will be sometimes for a considerable part of a day as low as zero, or 0; and we shall be provided with a sufficient supply of heat, if we have enough at this state of the external thermometer, for it seldom remains so intensely cold more than a few hours.

Of the Heat for Stoves for Plants of the Torrid Zone.

150. It will not be so easy to maintain the heat

* These are the results of observations, continued two years, by Mr. Daniell; commencing with September, 1819. The characteristic features of the two years were, in the first a cold winter and a hot summer; and in the second a very mild winter, and a backward cold summer. (Quarterly Journal of Science, Vol. XII. p. 114.) For further particulars respecting the climate of London, I must refer to his Meteorological Essays, pp. 262 and 391. The mean annual temperature of Manchester is 48°, according to Mr. Dalton's comparisons and observations, continued twenty-five years. The mean temperature of January varying from 25° to 44°, and of July from 55° to 62°. (Annals of Phil. XV. p. 252.)

† Humboldt, Edin. Phil. Journal, IV. 38.

in a moist as in a dry stove, and the difference will be nearly in proportion to the moisture of the air in the stove. We may make the same calculation serve for both, by giving an additional quantity of heat in the cases where a moist heat is necessary.*

The form, and mode of finishing stoves, are various; and the quantity of heat depends so much on the construction, that a few remarks on this subject will perhaps be useful. It will be found most economical, when the ground can be well drained, to sink the floor of the stove two or three steps below the surface of the ground, and to build

* Mr. Wakefield of Northwich, appears to have first applied steam to warm hot-houses and stoves, in April, 1788. He applied it, however, in a very different manner from the present practice. The steam was raised by shallow copper vessels, placed on the flues: the principal part of the flues being under an arched vault beneath the tan or bark bed, the arch of the vault being perforated, to allow the steam to pass through to the bed. To give steam to the house itself, shallow copper pans were placed on the flues along the front of the pit. In 1792, a house on a similar plan was erected for Lord Derby, at Knowsley. Mr. Wakefield has given a very detailed account of the effect of this mode of heating by steam, in the Transactions of the Society of Arts, Vol. XVIII. pp. 353—398, or Repert. Arts, Vol. XIV. p. 235, first series. Count Zubow's steam pits produce a similar effect; a cistern of water warmed by steam pipes, is placed under a bed, and the water becomes a reservoir of heat, and also affords vapour to the bed. (Transactions of Hort. Society, Vol. III. p. 430, and Vol. IV. p. 468.) With proper attention to isolating the reservoir of heat, it is a very good method, and will be found one of the best substitutes for dung heat.

the walls hollow.* (See Plate IV.) Then, having settled the proper height for the kind of plants to be cultivated in it, a slope of about 34 degrees from the plane of the horizon will be desirable for the roof—that is, a slope of two perpendicular to three horizontal; the other part of the height, if any, being upright glass windows in front.

Where the front and sloping lights join, as at *b* in the section, (Plate IV. fig. 13.) there should be as little obstruction to the light as possible. And since wooden rafters must be made deep to make them strong, they intercept a great portion of light, whenever the sun's rays are not parallel to the sides of the rafters; hence I would prefer iron ones, which may be made of half the depth; but a little more breadth is not so objectionable, because it only obstructs the entrance of light in the middle of the day, when the sun is often so powerful as to render partial shade necessary, to prevent the plants from

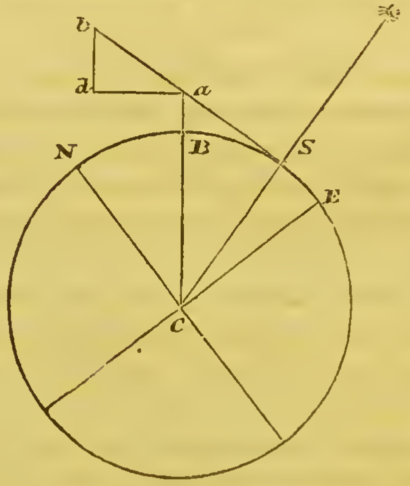
* The advantage of double or hollow walls is very considerable; and is claimed as a recent invention. Alberti, an Italian architect, who flourished in the sixteenth century, describes them, and reasons with great accuracy on their effects in confining heat. (Book X. chap. xiii.) Hollow walls are also strongly recommended by Vitruvius, but for a different purpose, his object in using them being to exclude damp. (Book I. chap. v.) The application of hollow walls to stoves is recommended by Bosc; and he thinks they would be improved by filling the cavity with pounded charcoal, or other slow conductors of heat. (Serre-chaude, Agricul. Ency. Méth.) And Dr. Parry proposed them as one of the means of avoiding dry rot in houses. (Repert. of Arts, XIII. p. 99.) So true it is "that the most important knowledge lies hid in books."

drooping under its influence: which is always greatest in a confined space.

In this construction, there is the advantage of keeping the house low, so as to be little exposed to loss of heat; and the upright glass is most favourable for admitting the direct rays of the sun, when it is not much above the horizon,* while the sloping roof of 34° will receive its rays nearly in a perpendicular direction at noon-day early in May.† All

* Bosc has, with much truth, remarked, "that it is in the morning that the influence of light has most effect on plants," and hence he prefers a south-east aspect for a stove, in order that it may receive the warmth of the day at an earlier period, and be less exposed to the western winds. (Serre-chaude, Agriculture, Encyc. Méth.) And Miller appears to have been fully sensible that the combination of upright and sloping glass is better than either singly. (Stove Gardener's Dict.)

† The method of determining the slope of a roof to receive the



the upright glass should be fitted in squares, or close glazed, in order to reduce the admission of air in winter, as that admitted at the laps of the glass in the roof* will be amply sufficient for the plants. To prevent any sudden influx of cold air, a porch, or an entrance through some other house, will be desirable.

sun's rays in a perpendicular direction at noon, at any place, and for any particular time of the year, may be useful to some of my readers. If the sun's declination for the proposed time be taken from the almanack, and subtracted from the latitude of the place when the sun's declination is north, or added if it be south, the result will be the angle the roof should make with the horizon in degrees. For example, the latitude of London is 51° 31′, and on the 6th of May, 1824, the sun's declination is 16° 36′ north,

Therefore, ... 51° 31′
Less, ... 16 36

34° 55′ the slope of the roof.

The reason of this rule will appear from these considerations. Let C be the centre of the earth; B, the place on its surface; B a the front of the hot-house; S C the direction of the sun's rays at noon at the proposed time; E C the equator; E S the sun's declination. Then, that the rays may fall perpendicularly on the line of glass S b, the slope of the roof should be perpendicular to S C; and in that case, the angle S C B is equal the angle bad; therefore, the $\angle ECB \mp \angle ECS = \angle bad$, when ad is a horizontal line.

* A good deal of attention has lately been given to the manner of glazing sloping lights, and, in consequence, it has been very much improved; glazing with circular laps was first introduced by Mr. Atkinson, and appears to be still preferred. An interesting review of the different methods has been given by Mr. Sabine (Trans. Hort. Society, Vol. IV. p. 84); and the method of circular glazing is described by Mr. Gowen. (Trans. Hort. Soc. Vol. III. p. 244.)

For ventilation when it is required, openings at the top are most effectual for letting out the heated air; and the openings for admitting cool air should be from the shaded sides of the house; that is, from the back wall, or at the ends, as most convenient: the height of the openings for cold air from the floor is not of much importance. This arrangement of letting in the cool air from a shaded side, will give great command in regulating the quantity of heat in warm weather, or when the sun is powerful.

151. To calculate the surface of pipe, the size of boiler, the quantity of fuel, and the quantity of ventilation, for a stove on this plan, will be the best mode of shewing how to proceed in other cases. Let us suppose the length of the house to be 30 feet, its width 12 feet, the height of the upright glass *a b* in front 4 feet, and the vertical height of the sloping glass of the roof 8 feet, and the whole vertical height 15 feet; the length of the rafters of the roof being 14 feet.—See the section, Plate IV.

The surface of glass in this house will be 720 superficial feet; that is, 540 feet in the front and roof, and 180 feet in the ends. Now, it has been shewn (art. 71) that, in a stove, half the vertical height in feet, multiplied by the length in feet, added to $1\frac{1}{2}$ times the area of glass in feet, will be equal to the cubic feet of air to be warmed in each minute, when there are no external doors; that is, $\overline{7{\cdot}5 \times 30} + \overline{1\frac{1}{2} \times 720} = 1305$ cubic feet. But in a house with wooden bars and rafters, about 1-10th

of this space will be occupied with wood work, which is so slow a conductor of heat, that it will not suffer a sensible quantity to escape; and, therefore, $\frac{1305}{10} = 130$ feet may be deducted: which gives the quantity to be warmed per minute, or $1305 - 130 = 1175$ cubic feet.

The surface of pipe to warm this quantity of air per minute when the external air is at zero, may easily be calculated by the rule (art. 44); thus, let the lowest temperature in the night be fixed at 50°, and allow 10° for winds, it will be 60°, which will be sufficient for a stove* (see art. 149;) then $\frac{60 \times 1175}{2 \cdot 1\ (200 - 60)}$ = 236 feet of surface of pipe. And since the length of the house is 30 feet, 5 pipes of 5 inches diameter will be about the proper quantity. (See Table IV. art 219.)

These pipes may be disposed, three along the front, and two along the back. (See Plate IV.) It has been usual to place them all at the front; but placing part at the back will be found useful, because the air in the house will be more regularly

* Bosc says, the temperature of a stove may vary from 66° to 77°, the mean about 72°. (Encyc. Méthod. Agric. Serre-chaude.) Miller had previously given the same range, and fixed on 62° for the lowest temperature that should be allowed in a bark stove. (Garden. Dict. art. Stove.)

According to Humboldt, the coffee tree, in order to be productive, requires a mean temperature of 65°. The olive requires a mean temperature of 61°, and that the mean heat of the coldest month should not be less than 42°. Edin. Phil. Journal, Vol. IV. p. 23.

changed, and the plants at the back of the house will thrive better. There should be valves for letting out steam into the stove, as described in the same plate, fig. 14.

Or the pit in the middle may be covered with flag paving, joined with Roman cement, and so as to form a close chamber into which steam may be introduced; some apertures will be required in the paving to afford a supply of steam to the matter in which the pots are placed, otherwise the dry bottom heat will most likely injure the roots of the plants. In situations where flag stones are easily procured, this will be a cheap plan, as much less pipe will be necessary—but not in other situations.

152. The space for steam in the boiler will be easily found by multiplying the length of the pipe in feet by the quantity of steam in a foot in length of the pipe: which is given in a table at the end of this work. (Table IV. art. 219.) In this case, the length of pipe is 150 feet, and the diameter 5 inches; therefore, it will contain $\cdot 1363 \times 150 = 20{\cdot}5$ cubic feet of steam. Now, to allow for filling the small conducting pipes, &c. we should have, in this case, a space for steam of about 25 cubic feet in the boiler; and it has been shewn, that 182 feet of steam-pipe will condense the steam of a cubic foot of water in an hour, (art. 46,) therefore, $\frac{236}{182} = 1{\cdot}3$; and we should have a boiler capable of evaporating $1\frac{1}{2}$ cubic feet of water per hour, to allow for loss of heat at the boiler. (See Chapter V.) And in the extreme case

of the thermometer being at zero, the consumption of coals will be 12¾ lbs. per hour; for 8½ lbs. of coal will convert one cubic foot of water into steam. (Art. 23.) Now, in less severe weather it will be best to allow the condensed water to collect in the pipes, during the whole time the steam is on; which, suppose to be for 8 hours, then, after the fire goes out in the night, the pipes will be almost filled with water nearly boiling hot, which will preserve the house warm till the morning.* See art. 117.

153. The quantity of ventilation for this stove will be found by the rule given in art. 72. Thus the length of the rafter is 14 feet, and the height of the front glass 4 feet, making a total of 18 feet; also the height from the floor to the outlet at the top 16 feet; then, by the rule

$$\frac{30 \times 18}{6 \sqrt{16}} = 22\tfrac{1}{2} \text{ feet.}$$

* To many who delight in having stove plants, M. Geo. Loddige's ingenious and easy mode of watering them, will be at once pleasing and useful. A leaden pipe of about half an inch diameter is conducted horizontally along the upper part of the house or stove, in a convenient direction for producing the intended effect. This pipe is in every part perforated with holes, being about the diameter of a fine needle, and about two inches distant from one another, but somewhat nearer together towards the part of the pipe which is most distant from the cistern which supplies the water. The cistern is placed above the level of the pipe; and as soon as the stop-cock is opened, the water issues through the perforations, and diffuses itself over the plants in the manner of a gentle shower of rain. (Transactions of Horticultural Society, Vol. III. p. 14.)

This is the area of outlet for the whole house, and may be divided in the manner best suited to the situation. Very high houses need less area for ventilation in proportion to their magnitude than small ones.

154. A mode of admitting fresh air so as to get the advantage of a sufficient current with very little attention, may be arranged by having air conduits, L L, beneath the floor, (see Plate IV.) with open gratings to let the air into the house; and one register, similar to the damper of a flue, to shut perfectly close when no fresh air is wanted. By this means there will be only one or two registers to open, instead of 11 or 12; there will, consequently, be fewer crevices to admit air in cold weather; the air brought in will be cooler and more effective in regulating the temperature—while, by disposing the gratings nearer together, in proportion to the distance from the register, the air may be introduced uniformly all over the house at the same time. In the section, fig. 13, Plate IV., we suppose that, on account of sheds behind the house, the air cannot be let in directly at the back wall.

The air conduit may be made of such dimensions as will admit half the quantity of air which has been shewn to be necessary (by art. 153) in very hot weather, and the rest may be admitted at the ends of the house.

The upper ventilators *f*, may be done in various ways: I have drawn in the section, the manner to which I give the preference. The flap of the

ventilator is intended to be opened or shut by a rod with a hook at the end; it will obviously remain open or shut from its own weight. Increasing the height of the top will add to the effect of the ventilation, and also prevent the cooling effect of northerly winds in winter.

Of the Heat for Green-houses to protect Plants, Orangeries, &c.

155. The use of green-houses for protecting plants is very considerable; and they are often of a superior style of architecture, in consequence of being immediately connected with the mansion. If orange trees be intended to be kept in the same house, a glass roof will be desirable, and a somewhat greater degree of heat than would otherwise be necessary. I shall therefore consider the two cases where a glass roof is used, and where it is not.

Green-house.

156. Suppose the house to be 40 feet in length, and 13 feet in breadth, with seven windows in front, each window 12 feet 6 inches by five feet, the area of the windows will be 437 feet 6 inches; and we may estimate the quantity of air admitted at each window to be 11 feet per minute; therefore (by art. 70) the whole quantity of air cooled per

minute will be $\sqrt{7 \times 11 + 1{\cdot}5 \times 437{\cdot}5} = 734$ feet per minute.

The house should be sustained at 40°, when the thermometer in the external air is at zero, then in the coldest season it will never be below 36°; and (by art. 44) $\frac{40 \times 734}{2{\cdot}1\ (200-40)} = 87$ feet of surface of pipe; consequently, two 5-inch pipes, each 30 feet long, will be sufficient. These may be put under the paving, with registers to let out the heat; but with more power above the floor along at the back of the house under the stage. The same thing may also be effected by having four cylindrical pedestals of about 36 inches in height, and one foot diameter, placed along the front; which would be more effectual, and not much more expensive than disposing the pipes along the back of the house, while they would be less objectionable in appearance. These pedestals would stand opposite the piers between the windows.

In the extreme degree of cold, the pipes, &c., will condense about a cubic foot of steam in 1·5 hours, and consequently require at the rate of $5\frac{3}{4}$lbs. of coal per hour.

Orangeries.

157. Let us suppose the house to be 40 feet by 13 feet, with the front and ends glass, with small piers between; the height of the front 10 feet, with a ridged roof 4 feet high, and glazed.

In this case (by art. 70) the area of glass will be about 1000 feet, when the wood-work is deducted; and $\overline{1\cdot5 \times 1000} + \overline{5 \times 40} = 1700$ cubic feet of air per minute, that will be cooled from the temperature of the house to that of the external air.

In a house provided for orange trees, it will be necessary to consult the habits of the tenderest species; and therefore we may limit the greatest degree of cold to 42°, and consequently have a sufficient quantity of heat to sustain the house at 46° when the thermometer is at zero.

Then, by art. 44, we have $\frac{46 \times 1700}{2\cdot1\,(200 - 46)} = 242$ feet.

The quantity of heating surface should be 242 feet; and may be disposed either in a plain or ornamental manner, according to the nature of the building, or the views of the owner. It will be an advantage to the plants to have a valve to steam the house, because steaming gives the leaves of the plants a beautiful freshness of colour.

Of the Heat for Forcing-houses, Pits, &c.

158. I will next proceed to give a few examples of forcing-houses; these, when kept flat, and partially sunk in the ground, are called *pits;* and are of the most economical form, though not well adapted for some kinds of plants. Pits are however best suited for other species, as we have an example in pits for pines; the arrangement of

which being considered, will be sufficient for the illustration of this part of our subject.*

Pine Pits.

159. For raising plants and bringing them forward, it is necessary to have separate pits; that wherein the plants are to fruit, was formerly named the stove, but now the fruiting pit. The fruiting pits are kept at a higher temperature than the other pits: Miller says the warmth in the winter should not be below about 66 or 67 degrees, nor higher than 78°;† but Mr. Knight has shewn that they will not suffer in winter by exposure to a much lower temperature in the night; and Mr. Neill‡ states that the temperature of the pit in winter is kept as nearly as possible at 50°, therefore it will be sufficient if we provide for sustaining them at 60° in the coldest season, and independent of the heat from leaves or tan in the beds; as modern practice has shewn that a bottom heat of tan, &c., may be dispensed with.

* Pits of different kinds are often employed to raise young plants and to bring them forward, so that they may attain perfection at an earlier period when transplanted to the open ground. Pits for this purpose should be little exposed to the direct action of solar light, for such strong light rather retards than accelerates the progress of plants in this early stage of their growth; they should, however, be regularly supplied with pure air, that is with air which contains its full proportion of oxygen. In illustration of this subject see Dr. Thomson's Chemistry, Vol. IV. p. 309.

† Gardener's Dictionary, art. Ananas.

‡ Art. Horticulture, Supp. to Ency. Brit. 1820, p. 659.

Let it be supposed that the fruiting pit is formed nearly in the manner described by Baldwin,* 40 feet in length, with rafters 10 feet long, (see Plate V.) which gives 400 feet of surface for roof glass; the area of the glass at the ends 36 feet; and one door—then, according to the rule for hot-houses, art. 70,

$\overline{5 \times 40} + \overline{1\cdot5 \times 436} + 11 = 865$ feet of air cooled per minute.

And by art. 44, to keep the temperature at 60 degrees, when the thermometer is at zero, it will require $\frac{865 \times 60}{2\cdot1\ (200-60)} = 177$ feet of surface of cast-iron steam pipe.

Four pipes of four inches diameter, will have this quantity of surface: two of these pipes to go along the front, and two along the back, would be most effectual. But I would prefer three pipes of five inches diameter, two of them along the front, and one along the back. They would contain a greater quantity of hot water, for preserving the heat after steam had ceased to flow into them. A valve for steaming the pit will be required. See fig. 14, Plate IV. The whole of the walls should be hollow; and the pipes not suffered to touch the walls, by about $1\frac{1}{2}$ or 2 inches. By covering the back with slate, and ceiling it below, the quantity of surface of glass is reduced, while convenient space for getting at the plants is obtained. When

* Short Practical Directions for the Culture of the Ananas, or Pine-apple Plant. Warwick, 1818.

there is enough of glass to afford light to the plants, every additional quantity causes a direct waste of heat: but I do not think end-lights should be dispensed with, for that will prevent the plants from having the morning and evening sun. The same reason renders it desirable to give the bars and rafters as little depth as possible, in order that the quantity of shade may be less when the sun is near the horizon.

160. When the laps of the glass are closed with putty or with metal, a less quantity of heat will be required; but I am not satisfied that this complete exclusion of air is desirable, for I observe that where the laps are closed as much as possible, placing the plants near the glass is esteemed most beneficial. But whether the laps be closed or not, it would perhaps be attended with considerable advantage, to have the means of raising the plants to the glass in the day, and lowering them at night. Where a bottom heat of tan is not employed, this would be very easily managed; and the expense would be inconsiderable. I know that in many plants, the removal of them to a distance from the glass at nights is of considerable use.*

* Mr. Wecks obtained a patent, in 1808, for raising the plants of hot-houses nearer to the glass in the day. Repertory of Arts, &c. Vol. XIII. p. 33, new series. But the mechanism he proposed to effect this object is not well adapted for the purpose. A moveable frame for vines has been recommended, but more for training with facility than for removing them from the cold air next the glass.

161. The temperature of the fruiting pit, is to be regulated in summer by ventilation; and it does not appear to be desirable to suffer it to exceed 95° in general, though a heat of 100° or 110° may sometimes be allowed; hence the area of the ventilators may be determined by art. 72. The height of the column of heated air will be in our section about 9 feet, and the length of rafter 10 feet; therefore, by the rule

$\frac{10}{6\sqrt{8}} = \frac{3}{5}$ of a foot for each foot in length of house.

And $40 \times \frac{3}{5} = 24$ feet nearly for the area necessary for ventilation. Now it will be best to have lower ventilators for about 12 feet of this; and make the end windows to open so as to have complete command of the temperature, at the periods when the thermometer attains the height which is made the basis of our calculation. The cool air I would admit in the walk, and in the manner proposed for stoves. See art. 154, and Plate V. fig. 16.

Graperies and Peach-houses.

162. In the proportion of heat for graperies and peach-houses, we cannot make a difference that is worthy of being considered in the arrangement of the quantity of pipe; though the quantity of difference the experienced gardener must very well know it is necessary for him to attend to; and

consequently he must be furnished with the means of regulating the heat of the houses at pleasure. This may be done by having one of the lengths of pipe in each house so that it can be in action or not, as the gardener finds occasion.

Vines do not burst into leaf when the mean temperature is below 50°; and the average night temperature less than 40°; therefore, when forcing is commenced, these must be the lowest limits of the temperature of a vinery. If the forcing be conducted with a view to bring them forward rapidly, they ought not to be exposed to a night cold of 40°; but 50°, or at the least 46°, should be the lowest temperature; the day heat from 58° to 64°, in the warmest part of the day.*

Peach-trees will blossom with success in temperatures about 4° lower than those which cause vines to break into leaf—that is, mean temperature 46°, and average temperature of the night 35°.†

In estimating the heat necessary for such houses, the higher temperatures must be taken, because the

* From latitude 36° to 48° is esteemed the favourite climate of the vine on the old Continent; the annual mean temperature of this band is from 50° to 62°, and the mean of the winter months not less than 36°. See Humboldt on the Distribution of Heat; Edin. Phil. Journal, Vol. IV. p. 24: or the art. Physical Geography, p. 178, Napier's Supp. to Ency. Brit.

† Humbolt says, "when the mean temperature of a month rises to 42°, the peach-tree (*Amygdalus Persica*) flowers." (Edin. Phil. Journal, IV. p. 32.) The temperatures given in the text are from my own observations.

means of rapid forcing should be provided to suit those who desire early fruits, in preference to fine flavoured. Therefore we should have the means of maintaining them at 50° in the coldest season, or when the thermometer is at zero.

163. But the nature of the houses must be considered in order to give an example. The form which is now adopted, almost universally, is very simple; it consists of a sloping glass roof placed at an angle of about 45° with the horizon,* and sustained by a low wall in front, and resting against a back wall of proper height; the ends being glass down to the level of the front wall, which is usually about two feet in height from the surface of the ground. A house of this kind appears to answer very well for vines; though it may upon trial be found that the construction I am about to propose for peach-houses, will be equally good for producing grapes.

Let us suppose a grapery to be 50 feet in length; the length of rafter 17 feet; and the area of glass at the ends 144 feet; the ends close glazed; and two doors. Then by the rule for loss of heat, art. 71, we have

$$\overline{5 \times 50} + 1{\cdot}5\,(\overline{50 \times 17} + 144) + \overline{2 \times 11} = 1763$$

cubic feet of air cooled per minute, of which one-tenth may be deducted in houses with wooden

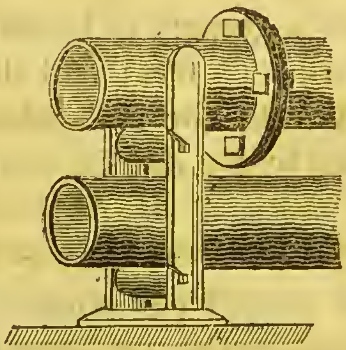
* The rays of the sun, at noon, will be perpendicular to a roof with this slope about the 6th of April, in the latitude of London. See note to art. 150.

lights; therefore, in that case, there will be 1590 cubic feet cooled per minute.

Again, referring to the rule for the surface of pipe, (art. 44,) and taking 50° to be the temperature for the house in the coldest season, we have

$$\frac{50 \times 1590}{2{\cdot}1\,(200-50)} = 254 \text{ feet.}$$

Four pipes, each of five inches diameter, will afford very nearly this quantity of surface; two of these should go along near to the front, and the other two near the back;* and if the steam boiler supply other houses, it will be an advantage to have one of the back pipes so that it can be in or out of action at pleasure. It will be proper to have a steam valve for steaming the house; a process which is found beneficial in checking the devastations of the red spider: see fig. 14, Plate IV. Where it is desired that only a small space shall be occupied by the pipes, they may be placed one over



* By putting pipes along the back, the plants trained on the back wall will do much better. Mr. Sabine (in the Hort. Trans.) recommends fig-trees as best adapted for the back walls of graperies.

another, as shewn by the sketch; which represents a standard with two rollers for the pipes to rest upon.

164. The quantity of ventilation for a grapery of this kind may next be considered. The length of rafter being 17 feet, and the height of the aperture, where the heated air escapes from, will not be less than 16 feet above the floor: therefore by the rule (art. 72,) we have $\frac{50 \times 17}{6\sqrt{16}} = 35\frac{1}{2}$ feet for the area of the space to let out the heated air, in order that the temperature of the house may not exceed 95° in a hot summer's day.* The same area should be formed for letting in cool air from the ends and the back part of the house. The end ventilators for admitting cool air in summer, should be carefully matted up or otherwise closed in winter; and when a little air is required, it would be an advantage to let it in at the central part of the house.

Peach-houses, of a new Construction.

165. In the open air we find that there is a material advantage in training peach trees against

* A self-acting ventilator may often save a crop of fruit. I am informed, by a friend, that Mr. Portcus of Darlington had one in use in 1807, which acted by the expansion of metal; and lately a very simple and ingenious one, which acts by the expansion of air, has been described in the Transactions of the Horticultural Society, Vol. V. Part iv.

a wall. It does not appear to be simply in consequence of the shelter the wall affords the tree; but more by retaining the heat received from the sun, and keeping up a higher temperature for a longer period of each day than it would be possible for a tree to have, when not attached to a solid and slow-conducting body.* Now if it be beneficial to nail a tree to a wall to increase the effect of the sun in the warmest season, will it not be attended with still more advantage to do so where we propose to bring the fruit to perfection at an earlier period, when the sun's heat is less powerful? With this view of the subject, I have designed the section of a peach-house, represented in Plate V. The walls B B for training the trees against are inclined, in order that they may expose a greater portion of surface in a more direct manner to the sun. The walls are intended to be built hollow, because they will be less expensive, and more easily constructed. The front is intended to have upright glass, in order to obtain the advantage of the sun's rays at an earlier and to a later period of the day, than when the whole is roof glass. It may also be worthy of remark, that there is no risk of breakage by frost in front glass when glazed in squares, and that it admits less cold air in winter than the lapped glass

* The long day and short night of high latitudes, are the most likely causes of the rapid vegetation during the short summer of these climates. The difference in the force of solar rays may also have some influence; as Mr. Daniell has suggested in his very interesting Essays on Meteorology, p. 229.

of a roof; and there is a less loss of heat from snow or rain.

166. The quantity of heat a house of this kind, 50 feet in length, will require, may be thus estimated, on the supposition that there should be the means of keeping it at 50° in the coldest season. In the sketch there is 3 feet of upright glass, and 11 feet of roof glass; therefore, there will be 700 feet of glass in the roof and front; and in the ends there will be 96 feet, making the total area 796 feet. Then, by the rule for loss of heat, art. 71, we have, supposing there to be two doors,

$$\overline{5 \times 50} + \overline{1{\cdot}5 \times 796} + \overline{2 \times 11} = 1466 \text{ cubic feet.}$$

This may be reduced one-tenth in houses with wooden lights, whence the cubic feet of air to be heated each minute will be 1320. The quantity of pipe that will afford heat for this purpose, by rule, art. 44, is

$$\frac{50 \times 1320}{2{\cdot}1\,(200-50)} = 209 \text{ feet of surface of pipe.}$$

Three pipes of the length of the house, and five inches diameter, would be sufficient; they may be arranged two at the front, and one in the back path: as shewn at S S, in fig. 17, Plate V.

To provide for ventilation in summer, the area of the top ventilators should be 32 feet, according to the rule, art. 72: for the length of the rafter is 11 feet, and the height of the front glass 3 feet, which makes 14 for the whole depth of glass; the

height from the floor to the aperture where the air escapes is 13 feet; therefore,

$$\frac{14 \times 50}{6 \sqrt{13}} = 32 \text{ feet.}$$

A considerable proportion of the cold air may be admitted by air conduits from behind the house, and the rest at the ends.

Hot Walls.

167. Steam heat may be applied with ease, and with many advantages, to hot walls. All that is necessary consists in conducting one or more pipes along the interior of a hollow wall. By the heat given off by the pipes the wall will be warmed, and without a risk of scorching the trees, in any part of it; the heat will be uniform throughout any proposed length of wall, and yet it will not be necessary to have many fire-places and chimneys, as in the ordinary method; which are objectionable, both on account of the smoke of the fires, and the attention they require. Hot walls have been very little used in comparison to what they were formerly; but when heated by steam, most of the objections against them would be removed; and this simple and cheap mode of producing fine fruit will be found well worthy of being generally adopted. If you have a thousand feet of wall to build, you may save as much by building hollow walls as will pay the expense of inserting steam pipes, and therefore there will only be the expense of a boiler and its apparatus required, to make it a

hot wall; and if you have other fruit-houses or green-houses to warm, the same boiler will serve for the whole—supposing them to be within a quarter of a mile of one another.

A good idea of the extent to which a steam apparatus may be rendered useful, will be formed by examining Plate IX. and the description opposite it.

CHAPTER X.

OF THE CONSTRUCTION OF GRATES AND OPEN FIRE-PLACES.

"Those fire-places are constructed on the best principles which throw the greatest quantity of radiant heat into the room they are intended to warm, and at the same time take away the least quantity of heated air."

GILBERT.

168. A FEW remarks on the principles of constructing fire-places, in connexion with the preceding detail of the principles of managing heat, will be considered an advantage by some of my readers. It will enable those who have not studied the subject themselves, to know whether their grates are formed on good principles or not; and to choose those that come nearest to the proper form, and which are constructed of fit materials. It will have a further advantage, in calling their attention to the study of an important subject; placed before them under views considerably different from those in which it has hitherto been considered.

The chief object of an open fire is to afford warmth by radiant heat; it is in this respect that it differs from a stove. We may form a fire-place to afford heat by contact; but this is a subject of secondary consideration, or at any rate may be considered in

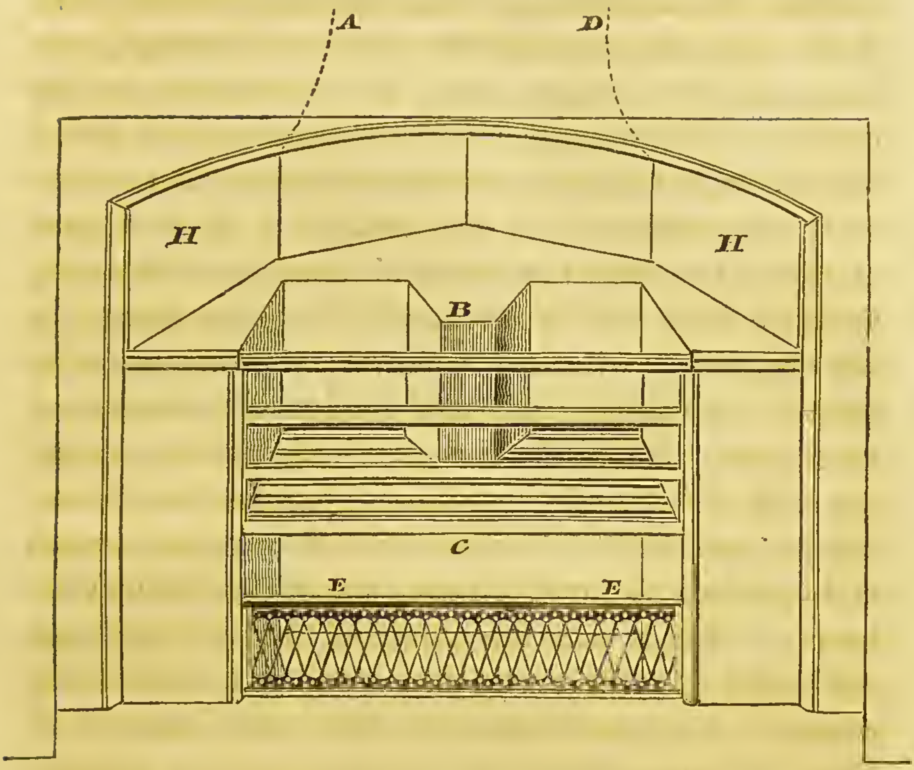
the second place, making the proper form and construction for giving out radiant heat the first.

169. Hot substances do not send out much radiant heat until they acquire a red heat; hence, the fire should be contrived in such a manner as to burn clear; and it is obvious that it should expose as much surface of burning fuel as is consistent with burning clear: consequently, the bars should not be larger than is necessary for strength; and no part of the fire should be boxed up in a case of iron, for the same reason.

170. We have seen that a clear fire is an advantage; and in order to attain it, the sides of the burning fuel should be at least half surrounded with slow conductors of heat; otherwise, the heat developed will pass off so quickly by conduction, that the fuel will burn dead; and that heat, which ought to be radiated, will be expended in warming the walls, &c. behind the fire. Iron is a very rapid conductor of heat, and therefore it should be used as sparingly about the fire as possible. Fire-brick, a slow conductor, is employed with much advantage for the backs and ends of grates by a few manufacturers: but ironmongers in general seem to think it more desirable to use iron, than to economize fuel or to work on sound principles.

171. But when a fire-place, made of slow conducting materials, is large, and filled with fuel, as soon as the fire becomes bright, the heat is extremely

intense and scorching; when the fire is in this state it is often too powerful for the room, though, perhaps, barely sufficient when the combustion is less perfect. This is easily remedied by a method which enables us to expose a greater surface of hot matter with the same bulk of fuel, and at a lower degree of heat: it consists in using a quantity of fire-balls, made of clay, and baked hard. They are placed in the fire, either stratified with the fuel, or put on as soon as it becomes clear and begins to give out too much heat. They produce their effect by increasing the bulk of hot matter, without affording heat themselves; and by this increase of bulk, a larger portion of hot surface gives off heat, yet of diminished intensity. But it must be admitted that fire-balls are extremely troublesome; they render it difficult to manage a fire, and it speedily goes out if neglected. Now, the same effect may be produced by another method. When a fire is of greater length than 18 inches, let a part of the back, B, in the figure, be made to project forward, so as to come within about 3 inches of the front bars of the grate. The projection should be of good fire-brick, and built firmly in with the other part of the back. It leaves the space for a sufficient body of fire on each side; and the surface is increased, without adding to the mass of burning fuel.



If the bulk of fire be contracted by making the distance of the back from the bars less than about six inches, the fire will never burn pleasantly; but by making the greatest depth six or seven inches, and making the back project forward in the middle, the fire is kept in sufficient masses to burn well without either an extra quantity of fuel, or an intense heat at the fire.

When the fire-place is less than 18 inches in length, this method of construction becomes unnecessary, and gives no advantage; neither will fire-balls be at all useful in so small a fire, if it be properly constructed and formed of proper materials.

172. The combustion in an open grate should be slow, because slow combustion is favourable for throwing off radiant heat; but it should not be slower than is necessary for a clear fire. The chief loss of heat being caused by the warm air of the room ascending up the chimney, it has been attempted to guard against this loss by contracting the throat of the chimney, and bringing down the mantle near to the fire, when it was necessary to increase the draught. But though this method may, in a great many instances, be successful, it will generally be at the expense of an increased consumption of fuel. Most of our smoky rooms are a consequence of the flues being too large:—they must be of sufficient size for a sweep to climb up them, while the present mode of cleaning them is continued; and they are made of the same size for all kinds of rooms, whether the fires are to be large or small, unless in a few instances where they are made of greater area for kitchen fires. The reader who has considered art. 93, 94, and the note, will easily perceive that, when a chimney is too large for the fire, there must either be a great loss of heat in warming air sufficient to fill the chimney with an ascending current; or that, in consequence of smoke being heavier than common air of the same temperature, in a wide chimney it may often happen that it will be so much interrupted and cooled* as to de-

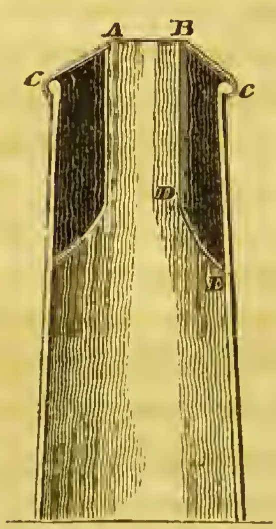
* In tall sheet-iron tops the ascending smoke must be much cooled; these additional tops ought always to be either made of a slow conducting material, or coated with one.

scend and impel the smoke, which is rising from the fire, out into the room. When all flues are made of the same size we can apply only a partial remedy, and the most effectual one is, to contract the aperture at the top of the chimney to the proper size. To fix the proportion, I have observed, that for each three inches in length of a grate of the usual proportions, we may estimate one lb. of coal per hour at an average, but that it affords about double the average quantity of smoke at first; and the effective excess of temperature in the chimney is about 16° when this quantity of fuel is necessary; consequently (by art. 93) it appears, that the area of the section of the chimney must be sufficient for $\frac{450}{3}$ cubic feet of smoke to escape in an hour for each inch in length of grate; and making the necessary allowance for ventilation, we have this simple rule:—

Rule.—Let 17 times the length of the grate in inches be divided by the square root of the height of the chimney in feet; and the quotient is the area for the aperture at the top of the chimney in inches.*

* Resuming the equation, (art. 94, note,) we have, by putting $l \times \frac{450}{3} = B$, $t' = 52°$, and $t - t' = 16°$; $\frac{15 \cdot 8\, l}{\sqrt{h}} = a$. When l is the length of the grate in inches, h the height from the fire to the top of the chimney in feet, and a the area of the outlet at the top in square inches. But a certain portion of air must escape for ventilation; and as our principles (art. 61) will give about 250 cubic feet for every three inches in length of grate, hence we should make $\frac{17\, l}{\sqrt{h}} = a$; which is the rule in the text.

The top of a chimney already fixed, may be easily contracted to the required area in this manner: Make a cap of copper or of plate-iron, well painted, so that it will slide into the chimney-pot or the top of the chimney. The form best adapted for the purpose, is shewn by the annexed sketch; which shews a section of a chimney-pot with the contracting cap inserted. A B is the aperture to be proportioned by the rule; C A a sloping conical surface, which will often prevent the wind's effect in forcing the smoke down, (see p. 91); D E shews the rounded form given to the interior, to prevent eddies and direct the smoke in an easy curve to the outlet; and a portion, B D, of regular diameter, I find to be necessary.



Example.—I had a grate of 15 inches, with a chimney 36 feet high, to which the contracting cap

was to be fixed. Now, $17 \times 15 = 255$, and the square root of 36 is 6, therefore, $\frac{255}{6} = 42\frac{1}{2}$ inches for the area of the cap at A B, and the diameter of a circle of $42\frac{1}{2}$ inches area is very nearly $6\frac{1}{2}$ inches: that is, A B being made $6\frac{1}{2}$ inches diameter, it will be sufficient for a fire 15 inches long with a chimney 36 feet in height. If the pot be formed to the shape with Roman cement, it will be better and more durable.

When the top is properly contracted, a register at the throat is not wanted; and it is always desirable to do with as little machinery about a fire as possible. I make the contraction at the top, to reduce the opposition which either the wind or even the resistance of the air makes to the ascending smoke, to prevent the chimney being cooled by double currents of air,—which very often will be found, in wide chimneys, and to reduce the loss of heat which must be required to sustain a current of smoke in a large flue.* If you were to make your contraction only at the throat, the force of ascent would be diminished at the first effort—it is like contracting the aperture of a pipe which supplies a jet—besides leaving a larger opening at the top than is necessary, for rain, cold air, &c. to descend and interrupt the smoke.†

* The advantage of contracting the top was first shewn by Clavelin; and it has been also noticed lately by Mr. Gilbert in the Quarterly Journal of Science, Vol. XIII. p. 119.

† The addition of the cover represented in the figure in p. 92, will be often useful.

173. The quantity of contraction near the fire, should be about the same as that at the top of the chimney, and all abrupt changes of form should be avoided; the chimney throat should not be of greater width than the length of the grate, and so situated that the smoke may rise nearly in a perpendicular direction; and that the heated air, which, passing under the mantle, flows into the chimney, may follow a curved surface till it mixes and rises with the smoke. The dotted lines A D, fig. to art. 171, shew the form of the contracted throat in one direction; and the breast should be rounded in the same manner, the back being made vertical. If these directions be too brief, a little attention to the motion of fluids will do more towards informing the young inquirer what is meant, than a dozen examples; the writers on hydraulics and pneumatics will, in some degree, prepare him for making his own observations, but it must be on these that he must chiefly depend. A little smoke or vapour may be employed to render the effect of obstructions and opposing currents visible; one artifice will lead to another; and, one case examined, the advantage of studying others will be apparent; and the result will be a feeling of true knowledge of the nature of every action which takes place, which gives confidence and power both in design and execution.

174. A grate should offer as little obstruction as possible to the radiation of heat from the fire, the bars should not be more bulky than is

necessary for strength, and there should not be a massive piece of metal work at C (fig. to art. 171), between the grate and the ash-pit. If it be wished to prevent the ashes being seen, a screen E E, across the lower part of the fire-place, as shewn in fig. to art. 171, will answer the purpose, and without intercepting that radiation which is most effectual in warming the hearth. There will also be some advantage in making the bottom grating of the fire to dip towards the back, about in the proportion of one inch in six inches—then the ashes will tend to the back. The form of the grate bars may also be somewhat improved, both in point of offering less obstruction to the radiation of heat, and in retaining the ashes within the grate. The form I would prefer is sketched in the margin: B is the front of the bar, and D the part next the fuel: cinders falling on the upper side, A, would not roll out to the front; and the advantage in offering less obstruction is evident.

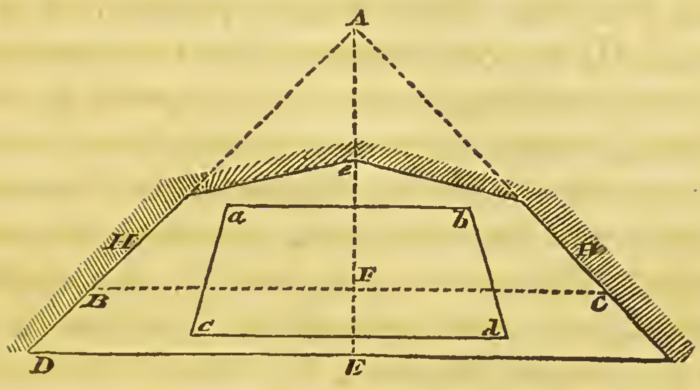
175. It has been shewn that we should have only a small quantity of metal in contact with the fuel (art. 170); but there is no objection to employing metallic surfaces, so that they may act as reflectors of heat; only they should not be any

where in contact with the bars or other metal round the fire. The covings, or sides, of a fire-place H, H, are now commonly placed in an oblique position, according to the plan proposed by Count Rumford, whose object in giving them such a position, was to reflect the heat into the room.* But to gain any advantage by reflection, the matter of which they are formed should be capable of reflecting the chief part of the heat which they receive; instead of which we most frequently find a blackened surface. Bright or polished surfaces are best for reflecting heat; and it has been shewn, by Professor Leslie, that brass is a more powerful reflector of heat than steel,† and consequently better adapted for the ornaments round a fire-place. Glazed surfaces of a light colour are good reflectors; and if covings were covered with Wedgewood ware of tasteful patterns, a greater quantity of heat would be reflected, and a new and lively appearance would be given to fire-places. I have mentioned a light colour, but perfect white should be avoided, because it is not so agreeable to the eye as other colours.

To determine the position of the covings H H, so that they shall be best adapted for reflecting the heat of the flame into the room; we may consider F to be the focus of the fire, then if D A,

* The original proposer was Gauger, in his "Mechanism of Fire made in Chimneys," London, 1716; which was first published in French in 1713.

† Inquiry into the Nature of Heat, p. 98.



be at an angle of 45° in respect of D E, the heat from a portion of flame at the focus F, would be reflected into the room in a direction perpendicular to the line D E, which here represents the front of the grate. The angle of incidence being equal to the angle of reflection, which is the condition required to be fulfilled. The same will be true of a portion of flame at any other part of the fire. Therefore, to set out the covings so that they will reflect the heat with advantage into the room, make E the middle of the front of the grate, and E D half the width which is convenient for the opening, and make A E perpendicular, and equal to D E; then join A D, and it is the direction in which the coving should be placed. A greater obliquity would be still more effective, because it would spread the rays more into the room, but is not convenient in other respects. The back of the fire is usually straight; but, unless the fire be small, it is an advantage to make the back in two parts, forming an obtuse angle at *e*; in this

angle the smoke collects and ascends with less obstruction that when it is dispersed over a flat surface. It is not necessary that the form of the fire should be regulated by the position of the covings, because its form does not affect the reflection; on the contrary, acute angles should be avoided, and the fuel kept as much in mass as possible. The form for the fire, marked *a*, *b*, *c*, *d*, in the figure, is drawn with the angles as acute as they ever should be made.

176. The height of the grate from the floor of the room is an object of some importance: if it be placed too low the heat is expended almost wholly on the hearth, and the fire-place seems buried within the fender. If it be placed too high a person's face is scorched, while too small a portion of heat is given to the floor, to render a room comfortable; but a high mantle has some advantage in producing a more effectual ventilation. After an attentive consideration of the reasons which determine this point, I am of opinion that the top bar of a grate should not be less than 20 inches from the floor; nor, perhaps, will it be desirable to exceed two feet. And when the lower part of the fire is not buried in a mass of metal work, there will be an abundant supply of heat thrown upon the floor with the greater height. The space between the top bar and the mantle, will require to be proportioned according to the size of the room and draught of the chimney, and in ordinary cases may be about 15 or 16 inches,

177. The proportions of grates for different sized rooms, I shall give entirely from observation, because it would require some more accurate experiments than I have yet made, to reduce these proportions to a rule, by an investigation from first principles. Investigation I always prefer, and consider comparison with practice as a kind of test, or proof, of the true principles having been taken; but I was foiled in the means I employed in experiments to obtain an accurate measure of the decrease of heat; and had not an opportunity to renew them by other methods.

If the length of the front of the grate be made one inch, for each foot in length of the room; and the depth of the front be half an inch, for each foot in breadth of the room, the proportions will be found tolerably near the truth in the cases usually occurring in practice. If the length of the room be such as requires the grate to be longer than $2\frac{1}{2}$ feet, two fire places will be necessary; and in that case the same proportions may be adopted, divided into two grates: unless the room be very wide, when a greater length should be given, and less depth, so as to preserve an equivalent area.

178. The ventilation of a room warmed by an open fire is defective,* because the air, which has

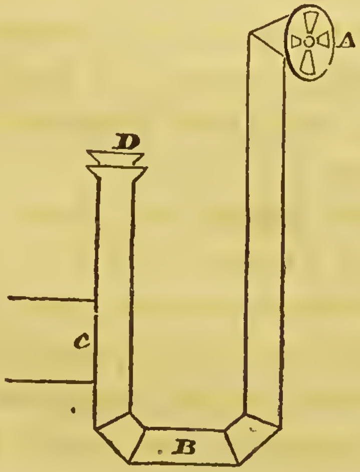
* An experiment made by Mr. Daniell illustrates this point; in his Meteorological Essays he thus describes it: "The temperature of a room being 45°, I found the point of condensation in it to be 39°. A fire was lighted in it, the door and windows shut, and no one was allowed to enter: the thermometer rose to 55°,

been rendered impure by respiration, &c., cannot be removed by the chimney as it is usually constructed. (See art. 62.) It has been proposed to improve this defect of our dwelling rooms by various means; but all that I have seen, or read of, are objectionable, either from being wholly inefficient, or from causing the chimney to smoke. Mechanical processes are troublesome, and hence are neglected; otherwise the object might be easily enough managed. To employ the heat of any other fire than that which warms the room which it is proposed to ventilate, would be to render two fires necessary instead of one, and perhaps after all not obtain the desired effect. I shall propose one remedy, which I have little doubt will be in a great measure effective.

If an inverted syphon be placed with one leg in the chimney, so near to the fire that the air in that leg will become warmer than the air in the other leg, motion will take place; for the air will ascend in the warm leg and go up the chimney, and a descending current in the cool leg will take the air from the room.

but the point of condensation remained the same. A party of eight persons afterwards occupied the room for several hours, and the fire was kept up; the temperature increased to 58°, and the point of condensation rose to 52°." (p. 204.) This experiment shews that, notwithstanding the constant current of air up the chimney, the quantity of vapour increased till the air in the room was nearly saturated. It would have been removed as it was formed, if the ventilation had been from the upper part of the room, and with it the effluvia and impure air.

To render the application of this principle successful, the mouth of the tube should be at the ceiling of the apartment; the lowest part of the curve should be, as much as convenient, below the point where the heat is applied; and the aperture through which the air flows into the chimney should be formed so that the soot may not fall down the tube—also the mouth of the tube should have a register to close it, or to regulate the ventilation. Thus, let A be the mouth of the tube, with its register at the ceiling of the room; C the place where



the leg to go up the chimney is brought in contact with the side or back of the grate; B, the lowest part of the curve; and D the mouth of the leg in the chimney, with an inverted cone to protect the mouth of the tube from falling soot. Such a tube may be easily placed in the angle of the chimney breast, or let into the wall. The branch or leg which goes up the chimney should be brought so

near to the fuel in the grate, as to receive a considerable portion of heat.

Where, by means of steam, the room is supplied with warm air, a method of ventilation of this kind will be most effective, and most necessary; and in a large room there will always be more heat required than an open fire can supply, so as to render the room comfortable to more than those immediately round the fire.

CHAPTER XI.

OF DRYING BY STEAM.

"On the rapid dispersion of moisture depends the efficacy of drying houses, which are too frequently constructed most unskilfully or on very mistaken principles." LESLIE.

179. THE art of drying by artificial heat is of great importance, in the small scale, in every family, as well as in the extensive manufactures of this country; therefore, every thing which tends to improve it must be useful. Very little has been written on the subject; yet it seems capable of being much improved by the application of the known principles of science. But, if it has not been treated of in books, it has been successfully cultivated in practice: so, indeed, as to leave very little to the writer besides generalizing the principles, regulating the power to the effect, and shewing to what cases each particular principle may be applied with the most beneficial results.

180. Steam heat is so pre-eminently safe for every purpose of drying, that, were it on this account alone, it would be preferable to any other; but it has also been found less injurious to the goods which are dried—for it neither communicates a harsh feel,

nor impairs the lustre nor colour of the brightest dyes.

It may be applied to drying muslins, calicoes, linens, yarn, paper, gunpowder, malt, hops, grain, sugar, &c.; and to laundries in domestic economy.

181. The usual process, at first, consisted in suspending the articles to be dried in a room, called a drying-room, kept at a high temperature. It was afterwards found that the process was expedited by admitting of some degree of ventilation. The next improvement consisted in applying thin goods directly to steam cylinders, and stretching others on frames which could be applied very near to them; and in some cases the cloth was made to glide along the hot cylinders in a serpentine direction, by which they were speedily dried. These arrangements, varied according to the nature of the articles to be dried, are found to be of excellent use: but something more was yet to be done to render the labour of attending the process less injurious to health; and this has been effected by Messrs. Strutts, of Belper, near Derby. The improvement consists in confining the heat to a place of sufficient magnitude to receive the goods to be dried, and so contrived that the workmen can change them with facility without being exposed in any material degree, to the intense heat and moisture of a drying room. Now, besides the inestimable advantage of being more healthy, this mode of drying is also more economical as to fuel; because we can employ a temperature, and a current of air, which it is difficult

to render at all effective in a large room. I do not intend to confine myself to any of these methods in exclusion of the rest, neither shall I adopt more of Mr. Strutt's idea, than that of inclosing the space to contain the goods; but while I endeavour to improve the application of any principles, I am glad of an opportunity of placing those I conceive to be the first discoverers before my readers, whenever I know them.

Principles of Drying.

182. All drying must consist in applying such a quantity of heat as will convert the moisture in the body into vapour; consequently, we have to consider how this may be done with the least expense of fuel and of attention—at the same time, to avoid as much as possible an expensive apparatus, and a large space of building.

183. The direct application of a high temperature will convert all the moisture into vapour in any goods of a thin light fabric;* and where quick drying is aimed at this will always be found the best method, but not in goods of a close texture and considerable thickness. And the same remark applies to drying bodies which are in powder or in

* It appears from a remark made by Mr. Snodgrass, that this method of drying muslins was practised in the bleach-fields near Glasgow in 1798. He says, it was effected "by wrapping them round hollow cylinders of metal filled with steam." Transactions of the Society of Arts, &c. Vol. XXIV. p. 119.

grains. They should be in small parts, thinly spread, and kept in motion when dried by the direct application of heat.

184. The direct application of heat might be aided by operating in a partial vacuum; but not in a material degree, because the expenditure of fuel would not be much lessened, while the difficulty and expense of the process would be very great. Yet, in articles of much thickness and small bulk it may be employed with advantage, in consequence of the moisture being partially forced out of the interior of the body, by removing the pressure of the atmosphere.

185. The next principle of drying depends on the affinity of air for moisture; this affinity is greatly increased by heating the air: the air produces an effect equivalent to diminishing the atmospheric pressure, but we have to heat it. Now, though air has affinity for moisture, it can absorb it only in the state of vapour; and therefore, as much heat as will convert all the water in the goods into vapour will still be required, besides that necessary to heat the air; the action of the air's affinity being chiefly effectual in accelerating the process of drying.* It

* The same power which fills air with vapour, would be called capillary attraction in a solid, when exerted on a liquid; and solution, when liquid acts on liquid, or liquid on soluble salts, &c. I consider the solution of a salt in water and of vapour in air, to be similar effects of the same power; it is a consequence of an attraction between the two bodies, which is insufficient to destroy

will be obvious, that dry air will act most powerfully; and, because cold air requires less moisture to saturate it than warm air, it will frequently happen that cold air will be most dry, and therefore most effectual in the drying room.

186. The external air is frequently very damp; and whenever that is the case, the manager of the drying stove should admit air more sparingly and work at a higher temperature, otherwise there will be a waste of fuel. For whatever air you admit carries off heat in proportion to the quantity, and if it be already saturated with moisture, it carries off

the equilibrium among the particles of either of them, otherwise a new compound would be formed; but it is capable of producing an uniform mixture. And so far is the idea of solution from being at variance with the doctrine of definite proportions, that when the doctrine is strictly analysed, it will be found, that chemical changes are simply alterations of the conditions of equilibrium among the elements of material bodies, and that it ultimately rests upon the same basis as mechanical science. Most of our writers on chemistry appear to think that Berthollet's notions respecting affinity would have agreed with the phenomena, if it were attraction of the same kind as planetary attraction; but the fact is, chemical changes can take place only when equilibrium is destroyed, every force less than that which destroys the equilibrium only produces displacement; and the effect of a mass of the decomposing body in the decomposition must necessarily be extremely limited, and to the extent of this limit it will be effective, as is abundantly proved in all chemical operations on the great scale. If you be an advocate for Mr. Dalton's theory, and deny that air has an attraction for vapour, you are obliged to imagine that in gas a repulsive force between its own particles exists; which seems incredible, unless it be to a disciple of Boscovich.

less water from the goods; but you give it the power of absorbing a greater quantity by raising its temperature,—and with a less expense of heat: as will be more fully shewn further on.*

The assistance of the affinity of air in drying, is most beneficial in goods of a thick close texture, woods, and the like.

187. Having considered the effect of external agents, we have next to inquire in what manner the goods themselves should be exposed to the heat. In all species of drying, it must be attempted to expose the greatest possible quantity of surface to the action of the air and heat, for the time will be nearly in the inverse ratio of the quantity of surface on which the heat acts; that is, if the surface be doubled, the time will be reduced nearly one-half.

188. The walls of the drying room (giving this name only to that part where the drying process is going on) should be of such a nature that they may absorb only a small quantity of moisture. They might be lined with glazed tiles, such as those called Dutch tiles, backed or fixed against some slow

* The Atmometer of Professor Leslie would be a useful instrument in a drying room; it measures the quantity of moisture exhaled by a humid surface in a given time, (art. Meteorology, Napier's Supp. to Encyc. Brit. p. 346,) for though its indications are not to be relied upon for many meteorological inquiries, it seems to be well enough adapted for the purpose here proposed. The methods which require the operations of weighing to be performed with considerable delicacy, would not be useful to practical manufacturers.

conducting matter. It would not be expensive to line the walls with thin slabs of common marble. If there be wood used in any part, it should be of a kind that will not yield colouring matter: hence oak, mahogany, cedar, &c., should not be employed. Small drying closets for private families may be made entirely of wood: the effect of warping must be prevented by employing narrow strips, ploughed and tongued together, and fastened with copper nails or wooden pins. See fig. 20, Plate VI. Iron should not be employed, on account of the rust that would be formed. The space inclosed should not be larger than is necessary for conducting the process with a proper degree of quickness.

189. The goods may be hung on frames, or stretched on them; always in such a manner as to afford the greatest portion of surface to the action of the heat. These frames should have wheels to each, in order that they may be easily moved backwards and forwards upon metal guide rails: or frames suspended as the sashes of a window may be often adopted with greater advantage than horizontal sliders, as the drying room may then be either above or below the workroom; and besides a saving of space, the changes can be made more easily.*

The frames on wheels or rollers are to be drawn out to put the goods upon them, and then wheeled into the drying room again; the space through

* The late Mr. Bramah had a patent, wherein a similar method of suspending the goods was proposed. Rep. Arts, Vol. VIII. p. 10, 1806.

which they are drawn out or moved in, being provided with doors to shut close, except during the times of changing the frames. Any frame ought to fit any of the spaces; and there should be at least one spare frame, so that the drying room may be kept constantly full. The number of spare frames will obviously depend on the convenience of the workmen in keeping the spaces constantly full. The height of the frames will determine the height of the drying room; but when it does not render them inconvenient for the workmen, high frames should be preferred: seven or eight feet will be about the greatest convenient height.*

190. The air should be heated before it enters the space containing the goods; and there should also be pipes between the frames for elevating the temperature of the goods. The heated air should enter at different places at the bottom immediately under the frames, and after passing among the goods, so as to become charged with vapour, it should go out at the top.† The outlets at the top over each frame

* A very convenient manner of forming the frames for drying many articles, will be to make them similar to Brierly's woollen-weaver's stretch or drying frame. (See Transactions of Society of Arts, &c. Vol. XXXVI. p. 62.) But the frame contrived by Mr. Rhodes for drying woollen warps, would be vastly superior, if it could be conveniently turned, so that the axis should be vertical, when placed in the drying room. (See Transactions of Society of Arts, Vol. XXXVII. p. 77.)

† Messrs. Strutts adopt a process exactly the reverse, they let the heated air in at the top and out at the bottom. Now, the

should lead to one, common to them all; which is to be provided with a regulator, to retard or accelerate the current, as circumstances may shew to be desirable; of course, there must also be a register to regulate the admission of cold air to the air chamber, where it is heated before it enters the drying room. By means of these registers, we shall be able to pass either a rapid or a slow current of air through any space in the drying room;* but the chief dependence must be placed on the upper register, because, if the lower one only be closed, it will cause so much draught through the crevices, and such an influx of air at every change of the frames, as will much interrupt the process. The register for admitting cold air, should be opened to such an extent as is necessary to prevent the greater part of the tendency of the air to enter from the working rooms.

As each frame must be at a distance from the adjoining ones, the progress of the current of air will be very different in the divisions; it will be most rapid through that containing the wettest goods, and slowest through that which contains the

warmest air, and that most charged with vapour, must be at the top, in consequence of its levity; and the hot air entering among this will become charged with vapour before it comes in contact with the goods, and therefore never act powerfully upon them.

* In some drying rooms, it appears, that pendulous fans were employed to agitate the air, (Buchanan's Essays on Heating by Steam;) but in a drying room ventilated in the manner we have described this will be wholly unnecessary.

ones which are nearly dry. For the velocity of ascent will be greatest where the air absorbs most moisture in a given time; but in all cases of drying, the quantity given off in a given time is always decreasing, till, after a certain period, it becomes insensible. The air which passes through the goods which are nearly dry, will go off without being saturated with moisture; but I do not, at this time, perceive a remedy, without a greater expense of labour than there would be saving of heat.

191. In goods of a thick texture, or in considerable masses, you may dry so quickly, that the drying will be only superficial; in such cases they acquire a harsh dry feel, and on being laid aside a few days, the internal moisture diffuses itself through them, and they feel damp. When this is found to be the case, a longer time and lower temperature must be taken for the process. The variation of the quantities of vapour given off at different stages of the process, renders it more difficult to compute the force of heat that will produce a given effect; because a greater quantity of air must pass through in the latter part of the process, than can be saturated with vapour. The superficial drying of loose matter may be prevented either by disposing it in thin layers or by constant stirring.

192. The weight of water which is absorbed by different bodies, is very different. I had paper, silk, linen, sail cloth, calico, and flannel tried, and calico

had been previously tried by Mr. Sylvester.* In my trials the different cloths were wrung as they usually are in washing, before being weighed in the wet state: the results approximate very nearly to—

	Weight dry.	Weight wet.	Weight of water absorbed.
Wool in flannel	1 lb.	3 lbs.	2 lbs.
Cotton in calico	1 —	$2\frac{1}{8}$ —	$1\frac{1}{8}$ —
Silk	1 —	$1\frac{29}{30}$ —	$0\frac{29}{30}$ —
Flax { in linen	1 —	$1\frac{3}{4}$ —	$0\frac{3}{4}$ —
Flax { in sail-cloth	1 —	$1\frac{3}{4}$ —	$0\frac{3}{4}$ —
Paper { foolscap	1 —	$1\frac{2}{7}$ —	$0\frac{2}{7}$ —
Paper { drawing	1 —	$1\frac{12}{50}$ —	$0\frac{12}{50}$ —

Now in order that equal weights of these different species of goods should be dried in equal times, the force of heat for the flannel should be sufficient to abstract 2 lbs. of vapour; while that for the calico need only be sufficient to abstract 1 lb.; and that for the linen three-qrs. of a lb. When the force of heat is equal for each species, the times are in a ratio much less simple. †

* Philosophy of Domestic Economy, p. 31. The results were, 547 lbs. dry, 1140 lbs. wet, and 593 lbs. of water absorbed: which nearly agrees with my experiment.

† Put W = the lbs. of water in the goods, and n W the lbs. evaporated in the first portion of time; then, the weight of water remaining in the goods at the end of 1′, 2′, 3′, &c. equal portions of time, will be $W(1-n,)$ $W(1-n)^2$, $W(1-n)^3$, &c. And if w be the weight they contain, when their power to absorb moisture is in equilibrium with that of the atmosphere at the mean temperature, we shall have $W(1-n)^t = w$, when the goods are dried; t being the time, and $t = \dfrac{\log. W - \log. w}{\log. 1 - \log. (1-n)}$.

Now, according to some experiments I have made, to ascertain

193. It will be found that the most economical rate of drying will be, when the quantity of moisture evaporated in a given time, is 0·08 times the whole quantity the goods contain; and the time each piece will have to remain in the drying-room will be about 30 times the given time, (see note to the preceding article.) The force of heat will depend on the quantity of water the goods contain, and the quantity of surface they expose to the action of the heat. The heat which may be taken as the most desirable to work at, in practice, will be 90 degrees, when the dew point is at 40 degrees; and it may easily be varied, so as to work with the same quickness when the dew point is higher.*

the weight of water that may be obtained from goods in a drying-room, that in ordinary language are said to be dry, it appears that w is about $\frac{1}{12}$ W; therefore, $t = \frac{1{\cdot}079181}{\log. 1 - \log. (1-n)}$.

But, we shall more frequently require to know the quantity to be taken off, in some aliquot of the time, on the supposition that the time is given; and then, $1 - \left(\frac{w}{W}\right)^{\frac{1}{t}} = n$; and when $W = 12\,w$, we have $1 - {\cdot}08\dot{3}3^{\frac{1}{t}} = n$. Let the time be 30 parts, then the logarithm of ·08$\dot{3}$3 divided by 30, gives the logarithm of ·9205; and 1 — ·9205 = ·0795 = n. Hence, if you wish to dry at the rate of W lbs. in 30 minutes, ·0795 W will be the quantity there should be evaporated per minute; and the frames should be charged in such a manner as will render the heat uniform. It is too complicated a subject to give in this place, otherwise it may be shewn by the principles of maxima and minima, that when the time is about 30 portions, the effect of a given portion of fuel is a maximum, when the goods are of such a nature that ·0795 W can be evaporated in the first portion of time.

* If we take a glass of water which is a little colder than that

194. The evaporation will be directly as the excess of moisture in the matter dried, when the matter and the time are the same;* and the time will be inversely as the supply of heat; but we cannot lessen the time by increasing the heat beyond a certain rate, which must depend on the facility with which moisture passes from the internal to the external part of the substance dried. To find the greatest quantity that might be taken per minute from a square foot of surface of cotton cloth, in a temperature of 90°, I tried several experiments, the mean of which gave nine grains, with the cloth saturated and the dew point at 40°;† and at this rate

temperature to which the air might be reduced, without causing it to deposit part of the moisture it contains, the surface of the glass will become covered with dew; and the temperature of the water when this deposition of dew begins, is called the dew point. When water of sufficient coldness cannot be otherwise procured, some nitre or muriate of lime may be added to the water. But it has been remarked by Dr. Young, (Lect. on Nat. Phil. I. p. 708,) that such experiments are liable to a slight inaccuracy, because some substances seem to attract moisture at a temperature a little higher than others; and he recommends the use of a metallic vessel in preference to one of glass. Mr. Daniell has lately contrived a very delicate instrument for ascertaining the dew point, which is described in his Meteorological Essays, (p. 144.) and three years of his observations give $44\frac{1}{7}°$ for the mean point of deposition for the neighbourhood of London.

* This is a general law, from which Mr. Dalton's particular one for the evaporation of moisture is easily established; but even from theoretical considerations we cannot expect it to be perfectly accurate, though so near as to answer every purpose in practice.

† Under the same circumstances the evaporation from a superficial foot of water is computed to be $22\frac{1}{7}$ grains per minute in

5400 square yards of surface, or 2700 square yards of cloth, would evaporate a cubic foot of water per minute, or nearly $\frac{1}{100}$ of a cubic foot of water for each piece of cloth.

195. Now, one cubic foot of air at 90° is saturated with 14·1 grains of steam, (see Table VI. art. 221.) and deducting 2·9 grains for the steam equivalent to that already in the air, when the dew point is 40°, we have 11·2 grains, or each yard of cloth will require about 15 cubic feet of air to carry off the vapour; but we cannot calculate upon the air being perfectly saturated, neither would it be desirable, because whatever is gained in this manner will be lost in time; and therefore we had better state it at 30 cubic feet; and for a piece of 25 yards, 750 cubic feet per minute.

196. Hence as soon as the balance of supply and expenditure of heat is established, the heat required per minute for each piece of 25 yards, will be equivalent to evaporating $\frac{1}{100}$ part of a cubic foot of water, and heating 750 cubic feet of air from the temperature of the external air to 90°.

calm weather; 29 grains in a moderate breeze; and 35½ grains in a high wind; from Mr. Dalton's experiments. But it would be desirable to have more experiments on this interesting subject; and particularly under the ordinary circumstances of evaporation and drying. Mr. Daniell has lately made a few, with a peculiar object, and which render it doubtful whether Mr. Dalton's numbers can be relied upon or not. (See Quarterly Journal of Science, Vol. XVII. p. 52.)

The quantity of steam-pipe required to evaporate $\frac{1}{100}$ of a cubic foot of water, is 138 superficial feet;* which should be of copper pipe, and disposed between the frames on which the goods are suspended.

To heat 750 cubic feet of air to 90°, supposing the external air at 40°, will require $\frac{750 \times 50}{2 \cdot 1\,(200-65)} =$ 132 feet. The calculation being made by art. 44, only the mean between 90 and 40 is here supposed to be the temperature in contact with the pipes. These pipes are to be placed so as to heat the air to 90°, before it comes in contact with the goods; and will be best made of cast iron, and placed in an air chamber under the drying stove.

It will be evident when the pipes are half of them in the air chamber, and half in the drying room, they will be very nearly in proper proportion; and the whole quantity will be 138 + 132 = 270 feet for each piece of cloth.

197. The manufacturer will be desirous of knowing the time this arrangement will consume to produce a given effect, as it cannot be reduced for calico without loss, or rather waste of heat. Let

* It is shewn (in a note to art. 46) that $\cdot 000738\, s\,(T-t) =$ 160°, whence $s = \frac{216800}{200-t}$. But, as it will require seven times this surface to convert a cubic foot of water into steam, $s = \frac{1517600}{200-t}$; and when $t = 90$, and the quantity only 100th part of a cubic foot $s = 138$ nearly. I suppose the heat necessary to generate a given quantity of vapour, to be the same at 90° as at 212°, as the difference is too small to bring it into the calculation.

us assume that a piece of calico contains 5 lbs. of water when put into the drying room, and we have found that the evaporation from calico may be 100th of a cubic foot of water in the first minute = ·625lbs. But 5 lbs. × ·08 (see art. 193,) is ·4 lbs. in the first portion of time, and it will be

lbs.		min.		lbs.		
·625	:	1	: :	·4	:	·64 min.

Hence, 30 × ·64 = 19·2 minutes will be the time of drying.

To dry in double this time, will require only half the quantity of surface of steam-pipe: and so of any other ratio. For domestic purposes about one third of this proportion of steam-pipe will be sufficient; that is, 45 feet in the drying closet, and 45 feet in the air chamber, for each 25 yards of cloth, or an equivalent surface of other matter.

198. The area of the pipe to convey away the steam, may be easily proportioned in this manner. There will be 750 cubic feet of air to pass through per minute for each 270 feet of surface of pipe, added to one-thirtieth part of its bulk of steam, making 775 cubic feet; with a decreased specific gravity equivalent to raising its temperature six degrees. Now, let the external air be at 40°, and the heated air to escape at 90°, the difference of temperature is 50°, and 6° for inferior specific gravity makes the whole difference 56°; and making the calculation by the note to art. 64, it will be found that dividing 7·75 by the square root of the height of the tube in feet, will give the area in feet.

The height must be measured from the centre of the hot chamber to the aperture where the steam and hot air go out into the atmosphere. Thus, if the height be 25 feet, the square root of 25 is 5, and $\frac{7{\cdot}75}{5} = 1{\cdot}55$ square feet, for the area of the tube for 270 feet of surface of steam-pipe.

All the passages for air will require about the same area. Therefore, when the quantity of steam-pipe is ascertained, the other proportions are easily obtained.

Family Drying Closet.

199. In order to illustrate the application of this mode of drying, the construction of a closet to dry linen for a family, is shewn in Plate VI. It is intended to have two horses, one of which will contain a sufficient quantity of linen, &c. to require about an hour to dry it; but when the first is about half dry, (which it will be in about twenty minutes,) another quantity should be put in upon the other horse. By this mode of changing them alternately, so that a fresh portion may be put in when the former charge is half dried, there will be a considerable saving of fuel as well as of time.

The horses move upon rollers; and when a horse is drawn out to the extent, the end closes the aperture, and prevents the escape of heated air.

In this method of drying, the persons who are

engaged in managing the process are not at all incommoded by the heat, nor by the steam from the wet cloth; a much less quantity of fuel is required, and much less space to produce the same effect.

For domestic purposes, there will be quite as little expense in fitting up an apparatus of this kind as the commonest in use. One of the boilers in the wash-house will answer as a steam-boiler, without rendering it the less fit for other purposes; those heavy and dangerous frames usually employed to hang the clothes upon will not be at all wanted; nor nearly so large a room for the laundry.

And it is not an inconsiderable recommendation to this plan, that an immense quantity of fresh air will have to pass through among the linen while it is drying, which must render it more pure and fit for use.

200. It will be sufficiently obvious that steam-heat may be applied to various other kinds of drying, where the advantage of a limited temperature will be greater than even in those cases which have been noticed. For many purposes it has been found useful, and I trust the principles and rules of this chapter will render it still more so. It will be seen what various circumstances ought to be considered, and it will not be a matter of surprise that success has not always been obtained by those who have not carefully studied the subject.

Steam-heat may be employed with advantage in drying *grain*, in *malting*, in drying *hops*, in drying

paper, *gunpowder*,* *sugar*, and other manufactured goods, &c.†

Steam may also be employed for drying peat for fuel; so that its preparation may not be confined to that part of summer when labour is most valuable. But there is a new and more important application to be considered; for in all districts where fuel is cheap, steam may be used with perfect safety to dry corn, in case of a wet harvest. An apparatus for this purpose would not be expensive, and would soon repay for the construction; a boiler and steam-pipes would form the chief part of the things wanted, in addition to what is usually to be found in any farm-yard. Hurdles would serve to spread the sheaves upon, and these might be laid horizontally upon cross bars, or poles, at about 18 or 20 inches apart. Tarpaulins or winnowing sheets, would serve to enclose the space through which the heated air should ascend, and circulate among the sheaves; and afterwards go out at the roof of the barn, or other building where the drying is conducted. A malt kiln with a steam apparatus, would

* In the art. Powder, (Napier's Supp. to Ency. Brit.) it is said that, "the method by steam-pipes has become generally adopted; and in this way, every possible security, real as well as imaginary, is obtained."

† Though steam heat is the safest and best for such purposes, in some cases it is desirable to employ other means; in a house which I lately designed for drying sugar, a uniform heat was given by stoves; the house is 50 feet long by 22 feet wide, and the stoves warm a quantity of air which passes over the surface of the sugar; and they also afford a regular heat to the plates on which it is spread.

make an excellent place for drying corn in a wet season; and I have no doubt, that in many districts the use of artificial heat will increase, and the loss of much valuable grain be prevented. Besides, with the knowledge that he can save his corn in good condition in a bad season, the farmer will have a mind more at ease: he becomes secure of that, which, in the ordinary course, is very frequently most seriously injured, and sometimes altogether lost. He may also turn the same contrivances to advantage in a wet hay harvest, and temporary erections will soon be changed for more permanent ones. The certainty of artificial heat will be to the farmer as important as the certainty of power is to the sailor; and those two classes of men, who have hitherto depended more than any other on seasons, will both receive great benefit by the application of steam.

It is not farmers alone that will be benefited by drying corn artificially in backward and wet seasons; for in such cases, the whole population must feel the good effect of this plan. Unsound grain makes very indifferent bread, doctor it as you like; and the evil is too frequently a very general one. When the grain is to be dried, a method of giving motion to the grain, and free liberty for the vapour to escape, has been recently invented by Mr. James Jones,* which will be of admirable use.

* Transactions of Society of Arts, Vol. XLI.

CHAPTER XII.

AN INQUIRY CONCERNING THE NATURE OF HEAT AND LIGHT.

"Although the invention of plausible hypotheses, independent of any connexion with experimental observations, can be of very little use in the promotion of natural knowledge; yet the discovery of simple and uniform principles, by which a great number of apparently heterogeneous phenomena are reduced to coherent and universal laws, must ever be allowed to be of considerable importance towards the improvement of human intellect."

YOUNG.

201. It is only by repeated efforts that we can hope to attain an accurate knowledge of the laws of nature, and of the constitution of natural bodies. But each individual, who has sufficient ardour and perseverance, may unfold some part of the veil which it has pleased Infinite Goodness to throw over the phenomena of the Universe; and accordingly, we find that an immense collection of facts, of reasonings, and analogies have been, from time to time, gathered on all subjects; and that these have been grouped into classes by the discovery of principles common to each class. This mode of classifying knowledge tends greatly to improve it, not only by rendering it easier to retain

that which is acquired and to use it with advantage, but also by suggesting new courses of experimental research, and consequently extending knowledge to new objects.

The nature of light and heat has not been unconsidered, yet nothing has been proposed that has been generally received as a true explanation of the phenomena; and having considered the subject in a manner a little different from any before proposed, I shall take this opportunity of making my readers acquainted with my speculations.

202. With a view of explaining several of the phenomena of nature, Sir Isaac Newton imagined that all space is pervaded by a highly elastic fluid, of extreme levity;* and which he has said may fill the spaces between the planets and other heavenly bodies, without producing an effect on their motions of which we should be at all sensible. Let it be conceived that this highly elastic fluid medium is caloric, or heat. Let it be further supposed, that heat and light are the same fluid, acting with different degrees of intensity. And with these suppositions, and a comparison of known facts, I propose to account for various phenomena; and I hope to leave my reader with an impression that the explanation is the true one, in every case where I am fortunate enough to make myself understood. As heat and light are here supposed to be the same fluid, the term caloric will be employed to denote

* See Newton's Optics; query 18th and 22nd.

the fluid in general, and the names heat and light will be used to denote it in the respective states of heat and light.

203. If two bodies be suspended in equilibrium in an elastic fluid, their surfaces will be every where pressed with the same force. But if a disturbing force causes these bodies to approach one another, the portion of the fluid between the bodies must necessarily require force to displace it, and consequently exert a pressure on the opposing surfaces, while there must be an equal diminution of pressure on opposite ones. Now, if all space be filled with caloric, the mutual attraction of the earth and sun, and the motion of the former, must cause an increased action of caloric on their opposing surfaces,* and hence we have the phenomena of light and heat on that side of the earth which is next the sun; while, on the opposite side, a diminished pressure of caloric is the cause of darkness and loss of heat; for a disturbance of equilibrium by diminishing the pressure must be attended with a loss of caloric, and the contrary effect must be a consequence of increased pressure, where all natural bodies are capable of absorbing the pressing fluid.

And it appears to be the increased pressure of caloric which acts on our organs of sight, and renders objects visible. We may be said to feel distant objects

* It may be said that the accumulation of caloric ought to be in the direction of the earth's motion in its orbit; but in a fluid so highly elastic, this cannot take place in a sensible degree. It can only be developed by the re-action of some other body.

by the intervention of an elastic fluid, whenever the sun's force increases its density in the atmosphere;* and this must happen, notwithstanding air or other grosser matter may occupy part of the space, whenever that matter is so constituted that the fluid caloric can freely pervade its pores.

If we carefully distinguish between intensity of action and quantity of action, we shall find no difficulty in making the distinction between light and heat. It appears that a certain degree of intensity of development is necessary to cause the phenomena of light, and that whatever quantity of fluid be acted upon, if the intensity be less than this degree, it will only cause the phenomena of heat; while great intensity and small quantity affords the phenomena of light without much heat: and we may conclude that this medium called caloric is universally diffused, and that in virtue of it we see the moon, the planets, and the fixed stars.

* For is it not more reasonable to imagine that the pressure of a fluid renders us sensible of the presence of a distant object, than that the object is continually either discharging minute particles of light, or reflecting them from its surface? As far as the doctrine of optics is concerned, the hypothesis of an elastic medium has been shewn to be the most probable in Dr. Young's Paper on the Theory of Light and Colours, (Nat. Phil. Vol. II. p. 613.) and I believe his hypothesis respecting light, differs from mine only in the one ascribing to undulation what the other states to be the effect of pressure; but I contend that the exciting cause of undulation must be pressure; and that where a fluid is moved through another medium by pressure, the transmission will be periodical. The extension of the hypothesis to heat has not the support of an equal authority.

Also, since when heat is forced into bodies by the mutual attractions and motions of the earth and sun, it does not and cannot immediately quit them as soon as the action has ceased; and as the expansion of the atmosphere must differ considerably on the eastern and western sides of a meridian on which the sun is vertical, may not this inequality be sufficient to cause the earth's diurnal motion?*

204. If any change take place in the equilibrium of an elastic fluid, the velocity with which it is propagated will be uniform, and equal to that a heavy body would acquire by falling through half the height of the modulus of elasticity of the fluid.† Now, it has been ascertained that the velocity of light is about 170,000 miles per second, therefore the modulus of elasticity of caloric will be about 25,000,000,000,000,000 feet; and the modulus of caloric being known, its density in any gaseous substance may be ascertained, if we neglect the effect of affinity; for the weights of the moduli must be equal for the same base, otherwise equilibrium would not take place. The modulus for air at 62° is about 27,800 feet; hence the density of air at

* If it be urged that a force constantly acting would produce an accelerated motion; I say, no; because this force overcomes an equivalent resistance in the friction of the fluid caloric the earth moves in; and continued acceleration could take place only during the time that velocity was generated which rendered the resistance equal to the moving force.

† Elementary Illustrations of the Celestial Mechanics of Laplace, art. 380.

62° being unity, that of the caloric it contains will be only $\frac{1}{870,000,000,000}$. Again, the modulus of water is 750,000 feet, or 22,000 times the weight of that air, and consequently the caloric in water, is at least 22,000 times as dense as that in air; but even in water it is about 40,000,000 times lighter than air at 62°, and therefore we need not be surprised to find that all attempts to weigh it have failed. If we could correct these calculations for the force of affinity, it would not materially alter the results.

205. When it is assumed that caloric is an elastic fluid, we must necessarily find its equilibrium and motion regulated by the principles of aërostatics and dynamics; and on these principles we have an easy solution of the greatest difficulties the subject affords. The phenomena of radiation, for example, are the same as would be produced by the accumulation of an elastic fluid at a particular place, or its disturbance by partial pressure. And it should be recollected, that in estimating the velocity of its movements in a dense medium, the absorption and resistance of the medium is to be considered.

206. When an equilibrium has been obtained, if it be again destroyed by the introduction of a fresh portion of caloric, different bodies will be found to absorb different quantities of the new portion of caloric in restoring the equilibrium. The peculiar quantity which each body absorbs under the same

circumstances, is denominated the *specific heat* of that body. In comparing the specific heats of bodies, that of water at 60° is supposed to be unity. If heat be a material fluid, the specific heat of a body may be computed, and in shewing that such computations agree very nearly with the best experiments, we shall obtain an additional proof of the truth of our suppositions.

207. If two bodies of equal bulk, but of different matter, be each heated one degree of the mercurial thermometer; and E be the quantity the one body expands, and ε the quantity the other expands; then the spaces occupied by their specific heats will be as their expansions, when no change of properties takes place. Therefore

$$E : \varepsilon :: 1 : \frac{\varepsilon}{E}.$$

But the density of heat in any body being as the weight of its modulus of elasticity, (art. 204,) and making M the weight of the modulus for the body of which the expansion is E, and m the weight for that of which the expansion is ε; we have, $M : m :: \frac{\varepsilon}{E} : \frac{m\varepsilon}{ME}$ = the specific heat of the body of which the expansion is ε; that of the other body being unity.

Making water the standard, when of the temperature 60°, and pressure 30 inches; we have $M = 326{,}000$ lbs., and $E = \frac{1}{3858}$; therefore $ME = 84{\cdot}5$, and

$\frac{m\varepsilon}{84\cdot5}$ = the specific heat of an equal bulk of a body of which the expansion is ε and modulus m.

Again, if we make S the specific gravity of the substance, that of water being unity, we shall have $\frac{m\varepsilon}{84\cdot5\,S}$ = the specific heat of an equal weight of the substance, when the same weight of water is unity.

Before attempting to point out the general conclusions which arise out of these equations, it will be desirable to compare them with the experiments which have been made in the most direct manner. First, atmospheric air at the temperature 60°, expands $\frac{1}{510}$ by one degree of heat, or $\varepsilon = \frac{1}{510}$, and the modulus is 14·75 lbs. when the barometer is at 30 inches.

Hence, $\frac{m\varepsilon}{84.5} = \frac{14\cdot75}{84\cdot5 \times 510} = 0\cdot000342$; which is the specific heat of air, that of an equal bulk of water being unity. The experiments of Delaroche and Berard make it 0·00032. The specific gravity of air is 0·0012, whence, $\frac{0\cdot000342}{0\cdot0012} = 0\cdot285$, which is the specific heat of air, that of an equal weight of water being unity; the experiments above quoted, make it 0·2669.

2ndly, Steam at 212° expands $\frac{1}{671}$ by one degree of heat, and its modulus is 14·75; hence $\frac{m\varepsilon}{84\cdot5} = \frac{14\cdot75}{84\cdot5 \times 671} = 0\cdot00026$, which is the specific

heat of steam at 212°, when that of an equal bulk of water at 60° is unity. And as the specific gravity of steam at 212° is 0·00058, we have

0·46 = the specific heat of steam at 212°, that of an equal weight of water being unity.

The specific gravity of steam at 60°, and under a pressure of 30 inches, supposing the steam could exist under these circumstances, would be ·0007053; and its specific heat 0·48, that of an equal weight of water being unity.*

3rdly, Iron expands $\frac{1}{143000}$ by one degree of heat, and the modulus is 25,000,000lbs.; whence,

$\frac{m\epsilon}{84{\cdot}5} = 2$ nearly, for the specific heat of iron, when that of an equal bulk of water is unity; and 0·263, when that of an equal weight of water is unity; experiments give from 0·143 to 0·11.

It is not attempted, in these calculations, to take into consideration the difference which a difference of affinity for heat must cause in its density; but I imagine, that if we could take this effect into consideration, the theory now proposed would be complete, and in its present state it approaches nearly to the truth. Since the expansions of all gaseous bodies are sensibly the same at the same temperatures, and the weight of the modulus the same at the same pressure, the specific heats of equal bulks

* It is said that "Mr. Watt has shewn, by direct experiment, that steam has a greater capacity as its temperature is lower." (Dr. Young's Nat. Phil. Vol. II. p. 409.)

ought to be equal, except so far as it is influenced by a difference of affinity for heat; and we find experiments to give results which approach nearly to equality. (See art. 217.)

As the weight of the modulus divided by the specific gravity, is a constant quantity in the same gas, and the expansion is the same at all densities,* the specific heat of equal weights will be the same. This conclusion is directly opposed to an opinion very commonly received, and which is said to be founded on experiment. If a delicate thermometer be placed within the receiver of an air-pump, and half the air in the receiver be quickly withdrawn, the thermometer will sink a few degrees. Also, if an extra quantity of air be quickly forced into a receiver the thermometer rises a few degrees. Hence, it is inferred that the specific heat of air is different at different pressures. But, do these experiments prove more than that, during a temporary derangement of equilibrium, mercury either acquires or loses a part of its heat, according to the action of the disturbing forces? and if it be true that heat is a fluid of the nature I suppose it to be, it is impossible that such a disturbance of equilibrium could take place without producing the effect which has been observed. The subject is of much importance, be-

* Assuming that the bulk of a gas is reciprocally as the pressure, it may be shewn that it will expand the same multiple of its bulk at all pressures. For, let A be the bulk at the temperature T and pressure P; then the bulk at any other pressure p, and temperature t, will be as $p : P :: A \left(\frac{450+t}{450+T}\right) : \frac{AP}{p}\left(\frac{450+t}{450+T}\right)$.

cause the law of gradation of heat in the atmosphere must remain unsettled till this point be determined.

The expansion by heat is not an equal quantity at all temperatures; consequently, the specific heat will vary according to the temperature of the body. When the body expands only a small quantity by heat, and the modulus is considerable, there will be no difference of specific heat that need be regarded in ordinary calculations: but in gaseous bodies the difference is considerable; according to my formula, the specific heat of air at 60° being 0·000342, that of air at 212° will be 0·00026. In some cases, the variation of specific heat in consequence of a difference of temperature, appears to have produced those effects which have been attributed to pressure.

208. On the assumption that heat is a material fluid, when it combines with any other matter, the combination may exist in *three* states; and these states must depend on the relative quantities of heat which enter into combination with the other matter. *First*,—When the quantity of matter is abundant in proportion to the quantity of heat, and the union of the parts, by their attraction, is vastly superior to their affinity for the heat interspersed among them. In this state the body is a solid. *Secondly*,—If the quantity of heat be increased in the surrounding bodies, this solid must also absorb its specific quantity to preserve the equilibrium: and the temperature may be increased to such a degree, that its cohesive power may be balanced by its affinity for heat. In this state the body is fluid. And *thirdly*,

—The temperature of a fluid may be increased till each particle becomes surrounded by an atmosphere of heat, which retains the particles at so great a distance from one another that their force of attraction is insensible.* The body is then in the state of gas. Hence it is that bodies assume those states at particular temperatures only; and the peculiar temperatures for each body must depend on the relation between its attraction of cohesion and its affinity for heat. A portion of heat enters into combination with the body at each of these changes, and which is called latent heat; or, perhaps with greater propriety, combined heat.

209. If two particles of the same matter be at a given distance in the fluid state, and attract each other with a power varying in any inverse ratio of the distance, and the caloric which retained them in equilibrium in the fluid state be removed by the attraction of surrounding bodies, the particles must evidently coalesce with momentum. Consequently, the rapid abstraction of heat must always render the contact most intimate; and when this is done to a certain extent, there are bodies where the affinity for heat is not sufficient to restore them to the natural equilibrium, unless they be subjected to an elevated temperature. The theory of annealing depends on this principle.

* A similar explanation is given in Playfair's Outlines of Nat. Phil. Vol. I. art. 331.

210. If a given quantity of water, of a given temperature, be converted into steam to support a given pressure, and H be the heat required when the temperature of the steam is T; then, $H + st - sT$ will be the heat required when the temperature is t, whether t be greater or less than T.

First, Let t be lower than T, and let the steam be formed at the temperature T; then, putting $s =$ the specific heat of the steam, the heat given out during the change of temperature from T to t, will be $s(T - t)$; consequently, the heat in the steam at the temperature t will be $H - s(T - t) = H + st - sT$.

Secondly, Let t be higher than T, then the heat to be added to produce the change of temperature will be $s(t - T)$; hence, the heat in the steam at the temperature t, will be $H + s(t - T) = H + st - sT$. Therefore, whether the temperature of steam be greater or less than T; the heat necessary to form it will be $H + st - sT$; when H is the quantity when the temperature is T.

If the change of temperature be considerable, the consequent variation of specific heat has to be considered; but this, though of great importance as a philosophical inquiry, will not make much difference in practice, provided the mean of the range be used. And with this limitation, we may easily determine the heat that would produce steam at any temperature, when that required at 212° is known. Now, it is found that as much heat as would increase the temperature of a given quantity of water 1127° would convert it into steam, the original temperature of the

water being 52°. Here we have H = 1127°, and let t be 90°, and the specific heat of steam ·847. Then, $212 - 90 = 122$, and $1127 - \overline{122 \times \cdot 847} = 1024°$ = the heat required to produce steam at 90°.

This very nearly gives the same result as Mr. Southern's supposition, that the latent heat of steam is a constant quantity;* for, according to his views, we should have $90 + 967 = 1057°$ for steam at 90°, and $212 + 967 = 1127°$ at 212°. The difference could not be detected by experiment on the small scale.

211. According to the principles that are assumed in this inquiry, all kinds of matter must contain heat, and in different proportions, according to the relations of their attraction of cohesion and affinity for heat; and therefore, we have an easy explanation of the phenomena of *combustion*. For, if several bodies enter into new combinations of such a nature that the total quantity of heat in the products be less than that the bodies contained before combination, there must necessarily be a portion of heat developed. So far this agrees with Dr. Crawford's doctrine of combustion. But caloric in the state of light is afforded by combustion; and this must happen, if our supposition be correct, whenever heat is developed in a concentrated state. Intensity should be carefully distinguished from quantity; and similar distinctions are necessary in the theory of sound.

* Robinson's Mechan. Phil. II. 166.

212. Again, when combinations are formed, of such a nature that the quantity of heat in the matter before combination is less than that the products would require to be in equilibrium with the surrounding matter, then cold will be produced.

213. When a greater proportion of caloric is in a substance than its specific quantity, it spreads in every direction by radiation, and with a force proportional to the density; and whenever the medium surrounding the body is of such extent and density, that the pressure of the heat which would radiate is not sufficient to put the heat already in the medium in motion, then radiation must be stopped, and the heat be distributed only by conduction. Hence, if a body developing heat be inclosed in a case of solid matter, the temperature of the external surface may be limited by the thickness of the matter. And also, whatever closes the pores of the case must retard the progress of the heat, such as polishing, burnishing, &c.; and, on the contrary, whatever opens the pores must render it easier for the heat to pass. Again, in hydraulics, we find that the addition of a short pipe increases the discharge of a fluid through an aperture, so also, in the motion of heat a thin stratum of porous matter increases the flow of heat.

214. I shall conclude this inquiry with applying the same principles to explain a phenomenon, which is usually considered one of the most decisive against the doctrine I support. It will readily be

granted that all solids contain heat. If you take one which is a good conductor, and let it be in contact with other conductors, and then contrive the means of removing the heat from a thin stratum at one end of the body, without altering its constitution, the heat would flow from the other parts of the solid till the stratum had again acquired its specific proportion; and if the abstraction of heat from a thin stratum were continually repeated, a continued flow of heat might be established through a conductor. Since the flow of heat is not in consequence of an additional quantity, but merely the motion of that quantity which is due to the body to maintain its equilibrium in respect to the surrounding ones, it must be obvious that the temperature of the solid ought not to be increased: indeed, if it be protected from the access of the heat accumulated, a decrease of temperature will have place. After the balance of abstraction and supply has obtained, the operation might be continued without limit. The generation of heat by friction, is an operation of the kind now described; and the blunt borer, employed by Count Rumford, forced the heat from a thin stratum of metal at each revolution. It is necessary that the operation should be continued with such velocity as will derange the equilibrium of heat in the solid, otherwise none would be expelled.

215. If I have, in any part of this chapter, expressed my opinion in too decided a manner, it was not my intention to do so: for, in a new view of a

subject of this nature it would be improper. But I trust it will be found worthy of attention. It requires no new affections of matter to explain the phenomena, and those necessary to its explanation are such as we are perfectly familiar with. There is nothing in it contradictory, nor at variance with the known principles of mechanics; and it reduces all effects to adequate causes. In this enlightened age, hypothesis being regarded only as an instrument for assisting research, it has no dangerous tendency; it is no longer binding than while it serves to connect known phenomena, and to indicate new objects of inquiry, at the same time it gives new interest in the search for knowledge. If a hypothesis be considered in this manner, it is infinitely less likely to mislead than the too common mode of generalizing from experiments.

[illegible]

TABLES.

TABLE I.

216. *A Table, shewing the quantity of Fuel that will Heat a Cubic Foot of Water one Degree; and the quantity that will convert a Cubic Foot of Water into Steam.*

Kind of Fuel.	Quantity in lbs. that will Heat one cubic foot of Water one Degree.	Quantity in lbs. that will convert one cubic foot of Water into Steam.
Newcastle coal (caking coal) -	0·0075	8·4
Splint coal, nearly the same -		
Staffordshire coal (Cherry coal)	0·0100	11·2
Culm - - - - - - - - -	0·0196	22·0
Wood (dry pine) - - - -	0·0172	19·25
—— (dry beech) - - - -	0·0242	27·0
—— (dry oak) - - - - -	0·0265	30·0
Peat (of good quality) - - -	0·0475	53·6
Charcoal - - - - - - -	0·0095	10·6
Coke - - - - - - - - -	0·0069	7·7
Charred Peat - - - - - -	0·0205	23·0

A bushel of Newcastle coals is usually estimated at 84lbs., and a cubic foot is about 50 lbs.; a cubic foot of solid coal is 79·3 lbs. A London chaldron is 36 bushels, it occupies a space of 62¾ cubic feet, and weighs about 28 cwt.* A Newcastle chaldron is about 53 cwt.

* The new measures for coals will be very nearly 3·15 per cent. greater than the old ones; therefore, the new chaldron will weigh 28·88 cwt. and the bushel 86 lbs.

TABLE II.

217. *Table of the Specific Heat, Specific Gravity, and Weight of a Cubic Foot of different Gaseous Bodies and Vapours.*

Temperature 60°. Barometer, 30 Inches.				
Gases.	Specific Gravity.	Weight of a cubic foot of Grains.	Specific Heat of equal Wts.	Specific Heat of equal Bulks.
Air, atmospheric - -	1·0000	527·0	·2669	0·00032
Alcohol vapour - -	1·6133	850·2	·5860D	
Ammoniacal gas - -	·5902	310·0		
Azotic gas - - - -	·9722	512·4	·2754	0·00032
Azote, protoxide of -	1·5278	804·2	·2369	0·00043
Azote, deutoxide of -	1·0416	548·9		
Carbonic acid gas -	1·527	803·8	·2210	0·0004
Carbonic oxide - -	·9722	512·4	·2884	0·00033
Carburetted hydrogen	·555	291·4		
Hydrogen gas - - -	·0694	36·6	3·2960	0·00029
Hydrogen, sulphuretted	1·180	621·9		
Muriatic acid gas - -	1·284	676·7		
Olefiant gas - - -	·974	513·3	·4207	0·0005
Oxygen gas - - -	1·111	585·5	·2361	0·000312
Steam* - - - - -	·625	329·4	·8470	0·00063
Sulphur vapour - -	1·111	585·5		
Sulphuric acid vapour	2·777	1463·6		
Sulphuret of carb. vap.	2·6447	1393·8		
Turpentine vapour -	5·013	2632·0		

* Steam is composed of (1 volume of oxygen) + (2 volumes of hydrogen condensed into one,) hence the weight of a cubic foot of steam is $\frac{585{\cdot}5 + (2 \times 36{\cdot}6)}{2} = 329{\cdot}35$ grains.

In the second Table, the specific gravity of the gases and vapours are taken from Dr. Thomas Thomson's valuable paper on the "Specific Gravity of Gases," in his Annals of Philosophy, Vol. XVI. p. 266; or from his System of Chemistry, Vol. III. The weight of a cubic foot in grains was calculated from those specific gravities making a cubic foot of air 527 grains. The specific heats, with the exception of that of the vapour of alcohol, are given as determined by Laroche and Berard. (Dict. de Physique, II. 201, Encyc. Méthod.) Alcohol vapour is from Dalton's experiments. In the one column, the specific heat of an equal weight of water is taken as unity; in the other column, the specific heat of an equal bulk of water is taken as unity.

In the rules of this work, I have considered the mean specific heat of air to be 0·297, that of an equal weight of water being unity; and the specific heat of an equal bulk 0·00035; for the experimental number in the Table is too low to be used in practice.

TABLE III.

218. *A Table of the Specific Heat, Specific Gravity, and Expansion of different Solid Bodies and Fluids.*

Substance.	Specific Heat of equal Bulks.	Specific Heat of equal Wts.	Specific Gravity.	Expansion by 180° of Heat.
Alcohol - -	·5	·59	·853	·11
Ashes (wood) -		·14		
—— (coal) -		·186		
Barley - - -		·421		
Beef - - -		·74		
Brass - - -	·92	·11	8·37	·0019
Brick - - -			1·841	
Chalk - - -	·63	·27	2·315	
Charcoal - -		·263	·332	
Cinders - -		·19		
Coal (pit) - -	·355	·28	1·269	
Copper - - -	·83	·095	8·75	·0017
Cotton - - -		·53		
Glass - - -	·45	·177	2·520	·00083
Gun metal - -	·897	·11	8·153	·00182
Iron (cast) - -	1·0	·14	7·207	·00111
—— (malleable)	·95	·125	7·60	·001258
Lead - - -	·34	·03	11·352	·002867
Lime (hydrate)		·40		
—— (quick) -		·22		
Mercury - -	·447	·033	13·568	·018
Milk - - -	1·01	·98	1·033	
Oats - - -		·416		
Oil (linseed) -	·496	·528	·94	·08
— (olive) - -	·457	·50	·915	·08
Oxide of iron -		·32		
Silver - - -	·58	·056	10·30	·00208
Stone ware -		·2		
Tin - - - -	·38	·052	7·291	·00248
Vinegar - -	·928	·92	1·009	
Water - - -	1·00	1·00	1·00	·0466
Wheat - - -		·48		
Wood (fir) -	·36	·65	·557	
—— (oak) -	·42	·51	·83	
—— (beech) -	·336	·48	·696	
Zinc - - -	·655	·093	7·028	·003

The specific heats of the metals, excepting iron, are from Dulong and Petit's experiments, the expansion of metals chiefly from Smeaton's experiments, and the other data of the Table selected from various sources. The specifie heat of iron is from my own trials.

TABLE IV.

219. *A Table of the quantity of Steam that will fill a given length of Pipe, and of the length of Pipe for one Foot of Surface.*

Interior diameter of Pipe.	Length of Pipe that will contain one cubic foot of Steam.	Quantity of Steam in one foot in Length of Pipe.	Length of Pipe that has one foot of exterior Surface.
Inches.	Feet.	Feet.	Feet.
1	183	·00545	3·28
1½	81	·01225	2·18
2	46	·02182	1·63
2½	29·2	·034	1·31
3	20·3	·049	1·09
4	11·5*	·0873	0·82†
5	7·3	·1363	0·66
6	5·1	·1964	0·55
7	3·7	·267	0·47
8	2·9	·349	0·41
9	2·25	·442	0·36
10	1·83	·545	0·33

* *Example I.*—Suppose it be required to know what quantity of steam 92 feet of 4 inch pipe will contain, by the Table 11·5 feet will contain one cubic foot, and $\frac{92}{11\cdot5} = 8$ cubic feet. Or it may be done thus: One foot in length of 4 inch pipe contains ·0873 of steam by the Table, and $\cdot0873 \times 92 = 8\cdot03$ cubic feet.

† *Example II.*—Suppose a room to require 200 feet of surface of pipe, and it is desired to know what length of 4 inch pipe will have this quantity of surface, then multiply 200 by 0·82; which gives 164 feet for the length of 4 inch pipe, which has 200 feet of surface.

TABLE V.

220. *A Table of the Expansion of Air and other Gaseous Fluids and Vapours, when not in contact with moist Bodies.*

Temperature.	Bulk.	Temperature.	Bulk.
60°	100000	60°	100000
59	99804	61	100196
58	99608	62	100392
57	99412	63	100588
56	99216	64	100784
55	99020	65	100980
54	98824	66	101176
53	98627	67	101373
52	98431	68	101569
51	98235	69	101765
50	98039	70	101961
49	97843	71	102157
48	97647	72	102353
47	97450	73	102549
46	97255	74	102745
45	97059	75	102941
44	96863	76	103137
43	96667	77	103333
42	96471	78	103529
41	96274	79	103725
40	96078	80	103922
39	95882	81	104118
38	95686	82	104314
37	95490	83	104510
36	95294	84	104706
35	95098	85	104902
34	94902	86	105098
33	94706	87	105294
32	94510	88	105490
31	94314	89	105686
30	94118	90	105882

Illustration of Table V.

As a formula of considerable simplicity, and yet of sufficient accuracy for practical purposes, is very desirable for calculating the expansion of gaseous fluids, I shall briefly deduce one, and compare it with the observations of Dulong and Petit.

Let T be the temperature when the bulk is B, and $\frac{B}{n}$ the increase corresponding to an increase of one degree of heat; and, suppose the increment of bulk to be the same for each degree of heat, then the expansion from any temperature, x, to any other temperature, t, will be $\frac{B(t-x)}{n}$; and the bulk at x will be $B + \frac{B(x-T)}{n} = \frac{B}{n}(n+x-T) = A$ or $\frac{nA}{n+x-T} = B$; and substituting this value of B in $\frac{B(t-x)}{n}$; and adding it to A, the bulk at x, we have $A + \frac{A(t-x)}{n+x-T} = A\left(\frac{n+t-T}{n+x-T}\right)$ = the bulk at the temperature t, that at x being A; whether the gas be expanded or contracted.*

If the bulk B corresponds to zero of Fahrenheit's thermometer, then $T = o$, and n is 450; whence, our formula becomes $A\left(\frac{450+t}{450+x}\right)$ = the bulk at the temperature t when that at x is A.

In a small table which follows, the correspondence of this equation with experiment is shewn; and it was em-

* The same formula will apply to the expansion of other bodies, when the proper value for n is ascertained. For water, T should be taken at 40°.

ployed to calculate the Table at the beginning of this article.

If we take B at 212°, then T = 212, and $n = 671$, whence we have $A\left(\frac{459+t}{459+x}\right)$ = the bulk at t, when that at x is A.

The correspondence of this equation with experiment is shewn in the experimental Table: it agrees best with the higher parts of the scale.

In the latter equation, when $x = 212°$, it is $A\left(\frac{459+t}{671}\right)$ = the bulk at the temperature t, when that at 212° is A.

In any of these equations, if t be below zero, it must be negative.

Table of Experiments.

	Temperature by Fahrenheit's Scale.	Bulk of Air by Experiment.	Bulk calculated by Equ. $A\left(\frac{450+t}{450+x}\right)$.	Bulk calculated by Equ. $A\left(\frac{459+t}{459+x}\right)$.
	— 32·8°	0·8650	0·8655	0·8680
Freezing point of Water . . .	32°	1·0000	1·0000	1·0000
Boiling point of Water . . .	212°	1·3750	1·3735	1·3666
	302°	1·5576	1·5621	1·5500
	392°	1·7389	1·7470	1·7332
	482°	1·9189	1·9336	1·9165
	572°	2·0976	2·1203	2·0998
Boiling point of Mercury .	680°	2·3125	2·3443	2·3201

This Table shews the expansion of air as observed by Dulong and Petit;* they found the expansion of hydrogen

* Dr. Thomson's Annals of Philosophy, XIII. p. 116.

to be very nearly the same, by the same change of temperature. Mr. Dalton's experiments give very nearly the same results within the range he tried; and Gay-Lussac found that air, vapour of ether, and steam, all expand the same by the same change of temperature; he found the expansion at 212°, the same as Dulong and Petit. According to Schmidt, the expansion from 32° to 212° is 1·3574.* And some late experiments of Sir H. Davy shew that the expansion is the same whether air be rare or dense.

In making experiments in the higher temperatures, it should be recollected that glass receives a permanent change of bulk in high temperatures, and particularly when unannealed.

In the table I have made 60° the standard temperature, because it is the one referred to by the majority of chemical writers; and is convenient from being about the temperature which is most usual in dwelling-rooms.

* Dr. Young's Lectures on Nat. Phil. II. 467.

TABLE VI.

221. *Table of the Expansive Force and Weight of Vapour of Water or Steam at various Temperatures.*

Temperature.	Force of Vapour. In inches of Mercury.	Force of Vapour. In lbs. per squ. inch.	Weight of a cubic foot of Vapour in grains.	Temperature.	Force of Vapour. In inches of Mercury.	Force of Vapour. In lbs. per squ. in.	Weight of a cubic foot of Vapour in grains.
32°	0·200	·098	2·3	130	4·366	2·14	42·3
40	0·250	·123	2·9	135	5·070	2·5	48·7
50	0·360	·177	4·0	140	5·770	2·85	54·9
55	0·416	·21	4·6	145	6·600	3·25	62·3
60	0·516	·255	5·7	150	7·530	3·7	70·5
65	0·630	·31	6·9	155	8·500	4·2	78·9
70	0·726	·357	7·8	160	9·60	4·7	88·4
75	0·860	·423	9·2	165	10·80	5·8	98·7
80	1·010	·495	10·7	170	12·05	5·95	109 0
85	1·170	·575	12·3	175	13·55	6·65	122·0
90	1·360	·67	14·1	180	15·16	7·55	135·0
95	1·640	·82	16·9	185	16·90	8·3	149·0
100	1·860	·915	19·0	190	19·00	9·35	167·0
105	2·100	1·04	21·2	195	21·10	10·40	184·0
110	2·456	1·21	24·6	200	23·60	11·60	204·0
115	2·820	1·39	28·0	205	25·90	12·75	222·0
120	3·300	1·62	32·5	210	28·88	14·20	246·0
125	3·830	1·89	37·4	212	30·00	14·75	254·7

TABLE VI.—*Continued.*

Temperature.	Force of Vapour.*			Weight of a cubic foot of vapour in grains.	The bulk of water being 1, that of the steam is	Height of a column of water equivalent to the excess above atmospheric pressure.
	In inches of Mercury.	In lbs. per square inch.	Excess above the pressure of the atmosphere in lbs. per square inch.			
212°	30·00	14·75	0·00	254·7	1718	0·00
217	33·50	16·50	1·75	282	1551	3·96
220	35·54	17·50	2·75	298	1470	6·25
225	39·11	19·30	4·55	326	1342	10·4
230	43·10	21·5	6·75	357	1225	15·0
235	47·22	23·3	8·55	388	1127	20·5
240	51·70	25·5	10·75	422	1037	24·5
245	56·34	27·7	12·95	456	959	29·6
250	61·90	30·5	15·75	498	879	36·0
255	67·25	33·1	18·35	537	815	42·0
260	72·30	35·6	20·85	573	764	47·5
265	78·04	38·7	23·95	614	713	54·5
270	86·30	42·7	27·95	675	648	63·4
275	93·48	46·0	31·25	726	603	71·5
280	101·90	50·0	35·25	786	557	81·0
285	112·20	55·2	40·45	859	509	92·3
290	120·15	59·5	44·75	914	479	102·0
295	129·00	63·5	48·75	975	449	111·5
300	139·70	68·5	53·75	1049	417	123·0
305	150·56	74·0	59·25	1123	389	136·0
310	161·30	79·0	64·25	1196	366	148·0

* Mr. Philip Taylor made a series of experiments on the force of steam, the results of which are lower than Dr. Ure's; but his mode of trial has not been described. His results, in a useful form, are given in the Phil. Mag. vol. lx. p. 452.

Illustration of Table VI.

In this Table the force of vapour in inches is taken from Dr. Ure's experiments :* and the weight in lbs. equivalent to the force in inches I have calculated ; and also the weight of a cubic foot of vapour, in grains at different temperatures, according to the specific gravity of steam as given by Dr. Thomson ; from which it appears that a cubic foot at 60° weighs 329·4 grains, when the pressure is 30 inches : and if f be any other pressure, we have

$$30 : f : : 329{\cdot}4 : \frac{329{\cdot}4f}{30} = 10{\cdot}98f = \text{the weight of a}$$

cubic foot at the force f and temperature of 60°. Let t be the temperature at the force f; then, it was shewn, in the illustration of the preceding Table, that $\frac{459+t}{459+60} = \frac{459+t}{519}$ = the bulk at the temperature t, supposing the bulk at 60° to be one cubic foot. Now the densities being inversely as the spaces the vapour occupies : it is

* Philosophical Transactions for 1818, Part II. According to Mr. Southern's experiments the force of steam at 250·3° is 60 inches of mercury ; at 293·4° it is 120 inches, and at 343·6° it is 240 inches. Mr. Southern also compared the density of steam at different temperatures ; at 229° water formed 1208 times its bulk of steam ; at 270° it formed 588 times its bulk ; and at 295° it formed 404 times its bulk. (Robison's Mech. Phil. Vol. II. p. 163.) My table nearly agrees with the first, and differs about one-tenth from the other two. Dr. Young has given a very convenient formula for calculating the elasticity of steam above 212°, it is $f = (1 + {\cdot}004\ (t - 212°))$, where f is the force in atmospheres, and t the temperature of the steam. Art. Steam-engine, Napier's Supp. to Ency. Brit.

$\frac{459+t}{519} : 1 :: 10{\cdot}98 f : \frac{5698{\cdot}6 f}{459+t}$ = the weight of a cubic foot of vapour in grains at the temperature t and force f, or with sufficient accuracy $\frac{5700 f}{459+t}$.

It has been ascertained that gaseous fluids, which do not chemically combine, mix together without condensation when the pressure is unaltered: and that when they are saturated, a cubic foot of air absorbs exactly a cubic foot of steam, as it would exist in a vacuum at the same temperature.*

If the bulk of the air be a at the temperature t; and f the force of vapour at the same temperature; and p the pressure of the atmosphere,—then, since the bulk a of air mixes with an equal bulk a of steam at the pressure f, the bulk of the steam at the pressure p, will be as $p : f :: a : \frac{fa}{p}$. And the bulk of the whole after mixture, will be

$$a + \frac{fa}{p} = \frac{a(p+f)}{p}.$$

As an example, take $f = \frac{1}{2} p$, then the formula gives $\frac{3a}{2}$ = the bulk: which nearly corresponds with the temperature of 180°. Now General Roy's air being 1000 at zero, it would be 1375 at 180°, and making $a = 1375$, we have $\frac{3a}{2} = 2062{\cdot}5$. At the temperature of 172°, it was found to be 1929·78 by experiment.

I ought to notice, that Professor Leslie has given a table of the quantities of moisture that air will hold in solution at different temperatures, which differs from mine, when reduced to the same measure of heat; perhaps owing to the results of his experiments leading him to consider that

* See General Roy's Experiments, Quarterly Journal of Science, Vol. XIII. p. 82; or Daniell's Meteorological Essays, p. 174.

while the increments of temperature are in arithmetical progression, the increments of moisture are in geometrical progression.* It is dangerous to follow analogies of this kind when they are not founded on the physical conditions of the problem; which there seems to be no reason for supposing that this analogy is.

Mr. Daniell has given a table of specific gravity of any mixture of aqueous vapour and air, calculated on very accurate principles, from zero to 90°;† and also a table showing the weight of a cubic foot of vapour in grains,‡ there being some difference between his results and mine, renders it necessary to remark that I have taken the force of vapour as Dr. Ure determined it by experiment; Mr. Daniell takes the force as calculated by Dr. Ure's formula, which is an empirical one.

* Art. Meteorology, Napier's Supp. to Ency. Brit. p. 342.

† Quarterly Journal of Science, Vol. XIII. p. 85; or Meteorological Essays, p. 178.

‡ Meteorological Essays, p. 157.

TABLE VII.

222. *A Table of the Latent Heat of Bodies.*

Body and State.	Latent Heat.	Authority.
Steam	967°	*Ure.*
Ammonia, vapour of, specific gravity ·978	837°	*idem.*
Bismuth, fluid,	550°	*Irvine.*
Tin, fluid,	500°	*idem.*
Zinc, fluid,	493°	*idem.*
Alcohol, vapour of,	442°	*Ure.*
Sulphuric Ether, vapour of,	302°	*idem.*
Naptha, vapour of,	178°	*idem.*
Oil of Turpentine, vapour of,	178°	*idem.*
Bees' Wax, fluid,	175°	*Irvine.*
Lead, fluid,	162°	*idem.*
Spermaceti, fluid,	145°	*idem.*
Sulphur, fluid,	143°	*idem.*
Water	140°	*Black.*

TABLE VIII.

223. *A Table of Temperatures.*

	Degrees of Fahrenheit.
Cast iron melts	3479
Gold melts	2590
Copper melts	2548
Silver melts	2233
Brass melts	1869
Heat of a common coal fire	1050
Red heat just visible in day light	980
Bodies shine sensibly in twilight	885
Hydrogen gas burns	800
Iron bright red in the dark	750

	Degrees of Fahrenheit.
Mercury boils - - -	680
Zinc melts - - - -	648
Lead melts - - - -	612
Linseed oil boils - -	600
Bismuth melts - - -	476
Tin melts - - - - -	442
Naptha boils - - - -	320
Oil of turpentine boils -	314
Alloy of tin and bismuth in equal parts melt -	286
Alloy of tin 4, lead 1, and bismuth 5, fluid -	244
Saturated salt brine boils	226
Water boils (bar. 30 in)	212
Alloy of tin 3, lead 2, and bismuth 5, melts - -	212
Alcohol boils (bar. 30 in.)	176
Bees' wax melts - - -	142
Ammonia boils - - -	140
Tallow melts - - - -	127
Greatest heat in the sun observed in England -	126
Heat of incubation - -	108
Pleasant bath - -	92 to 106
Pure ether boils - - -	98
Heat of the human body	95
Greatest heat in the shade observed in England	92
Summer heat - - - -	76
Acetous fermentation begins - - - - - - -	76
Temperate air - - -	62
Vinous fermentation begins - - - - - -	59
Mean temperature of England - - - -	52
Water freezes - - -	32
Milk freezes - - - -	30
Sea water freezes - -	28
Wine freezes - - - -	20
Greatest cold observed in England - - -	— 2
Mercury freezes - - -	—33
Greatest natural cold observed - - - -	—50
Greatest artificial cold produced - - - -	—90

ADDENDUM TO CHAP. IV.

ON THE ALTERATION OF THE PROPORTION OF THE COMPONENTS OF ATMOSPHERIC AIR BY WANT OF VENTILATION.

It was stated in art 55, p. 69, that chemistry had not been able to detect an appreciable difference between the composition of the air of a vitiated atmosphere and that of a pure one; and therefore it seems desirable to investigate the extent to which the composition of the air of a room can be alterated in ordinary circumstances.

Let us suppose a room to contain such a number of persons as will generate b cubic feet of impure air, and that the ventilation is v cubic feet of air in the same time; and, under such circumstances, that a uniform mixture of the pure and impure air must take place; also let the cubic contents of the room be B feet.

The impure air will become diffused through the space B, so as to be expanded into $\frac{B+v}{b}$ times the space it occupied when first generated, consequently, if a quantity of air $= b$ were removed, it would take away only $\frac{b^2}{B+v}$ of impure air; and as only v is to be removed by ventilation, we have

$b : v :: \frac{b^2}{B+v} : \frac{b\,v}{B+v} =$ the quantity of impure air removed in a unit of time by ventilation. After the

room has been occupied by the persons for a time t, the quantity of impure air removed will be to the quantity generated in the same time as

$$\frac{b}{m}+\frac{b\,m-b}{m^2}+\frac{(b\,m-b)^2}{m^3}+\ldots\ldots\frac{(b\,m-b)^{t-1}}{m^t}\ :\ b;$$

or as $1+\frac{m-1}{m}\ \left(\frac{m-1}{m}\right)^2+\ldots\ldots\left(\frac{m-1}{m}\right)^{t-1}\ :\ m;$

where $m=\frac{\text{B}+v}{v}$.

The sum of progression is

$m\left\{1-\left(\frac{m-1}{m}\right)^t\right\}$, and substituting for m its proper value, the ratio is

$$1-\left(\frac{\text{B}}{\text{B}+v}\right)^t\ :\ 1.$$

Now, whatever value we give to v, it is obvious that, in the case of complete diffusion, the whole of the impure air which enters cannot be removed if v be less than B, for in all cases where v is less than B, the time t must be infinitely great. Hence, we shall shew, that when there is a certain degree of ventilation going on, the accumulation of unrespirable gas approaches constantly to a limit which it never exceeds; for let n represent the quantity of unrespirable gas in atmospheric air; and let $x\,n$ be the quantity to which it approaches, but is not to exceed. If it did arrive at the proportion $x\,n$, then the consumption of oxygen would be exactly equal to the supply, and consequently no further change could take place. For $\overline{1-n\,v}$ would be the quantity of oxygen entering by ventilation, and $\overline{1-n\,x\,v}$ the quantity let out, therefore, the difference is the

supply which is equal $\overline{nx - nv}$. But the consumption in the same time is $\overline{1-n}\,b$, and the consumption will be equal to the supply when $\overline{1-n}\,b = nv\,(x-1)$ or when $x = 1 + \frac{\overline{1-n}\,b}{nv}$. In atmospheric air $n = \frac{4}{5}$ nearly, consequently $x = 1 + \frac{b}{4v}$, and a greater proportion of unrespirable air than xn cannot accumulate. One man generates 160 cubic inches of unrespirable air in a minute, hence $b = \frac{160}{1728} = \frac{1}{10{\cdot}8}$; or $x = 1 + \frac{1}{43{\cdot}2\,v}$.

The space allotted to one man in an hospital or in a prison, is about 600 cubic feet, and suppose the ventilation to be one cubic foot per minute, then $v = 1$ and $x = 1{\cdot}023$ or the quantity of unrespirable air will increase $\frac{1}{43}$ part, but never exceed that proportion. But with the ventilation of 4 cubic feet of air for each individual, the increase cannot exceed the $\frac{1}{172}$ part, even when the ventilation is conducted on the most defective principles; and it certainly ought to be a nice experiment to judge of the increase of $\frac{1}{172}$ part, considering the nature of the operation; and we have shewn that it would require an unlimited time to arrive at that degree of excess.

The accumulation of carbonic acid may also be considered in the same manner; its proportion in atmospheric air is stated to be $\frac{1}{1000}$ part; and

$$1 + \frac{1000\,b\,(1-n)}{v} = x; \text{ or } 1 + \frac{18{\cdot}52}{v} = x.$$

Consequently with a ventilation of one cubic foot

per minute, the proportion of carbonic acid will increase to about $\frac{1}{50}$ part of the air of the room, but will not exceed that proportion. If the ventilation be 4 cubic feet per minute, the proportion cannot exceed $\frac{1}{200}$ part of the air even in the most unfavourable circumstances.

If the order of investigation be reversed, the result must be equally true; hence it is, that continuing to inspire impure air, even when it is only in small proportion, must ultimately produce a serious change in the human constitution.

ADDENDUM TO CHAP. VIII.

A Letter from Dr. George Pearson to the Author on Houses of Equal Temperature.

Dear Sir,

The perusal of your plan for producing equal and warm temperatures, with at the same time effectual ventilation, not only in large buildings for public uses, but in small or ordinary sized dwellings, afforded me great satisfaction. The neglect of the public to avail themselves of these measures in countries enlightened by science would not be credible if the history of former times, and our own experience in later times had not made us acquainted with similar neglect of many other precious discoveries. One example may suffice to justify this remark, namely, the neglect of the employment of the agency of steam, amongst 100 other inventions of the Marquis of Worcester, indicated more than a century and a half ago, in his little book, "The Century of Inventions." For nearly 100 years this powerful agent was almost solely used for working machinery in mining; and although it was much talked of, it was only within the last thirty or forty

years that the application has been made of it for other purposes, especially with such astonishingly powerful effects in navigation. This is precisely the case with the methods invented for the warming of houses; the principles for this purpose are now well known to many persons: they have been fully developed, but only partially acted upon in practice within the last twenty or thirty years. The loss of comfort, and indeed of life, from the neglect now spoken of, is incalculable. But as a friend of mine expresses himself, "John Bull is a slow travelling animal." I have not failed to attempt to influence the public in favour of constructing buildings for warm and equal temperatures in my public lectures during thirty years past, and also occasionally during this time in the public prints, besides introducing in my private practice, contrivances, although rather rude ones, to accomplish this object. Among other channels of intelligence by me to the public, are those referred to in your publication, namely, the notices in the Philosophical Magazine of Tilloch, Vol. xxxi. 1808, Vol. xxxiv. 1809, and Vol. xxxv. 1810. Your plans for private houses will in all likelihood occasion improvements in the future constructions: but a grand Institution for the benefit of the invalid public, and the sick in general, by the erection of a building of sufficient space for apartments and rooms of various dimensions to afford warm and equal temperatures, is at this time especially an object for the gratification of the philanthropist, and, in all probability must be profitable to the pro-

prietors. To sueh a fabric as is here proposed, should be attached variously disposed spaees for pleasure walks, for green-houses, for baths, and for amusements. How many thousands of persons of all ranks are at this time living in the United Kingdom in a state of bad health, not remediable, or even capable of relief but by warm fresh air of suitable degrees of temperature? Such states of the atmosphere are no where obtainable, exeept perhaps for a short time, in any elimate. The more temperate climates afford the required temperatures during parts of the year only; and the tropieal latitudes from the extreme heat and the existence of the causes of disease are scareely preferable, some rare cases excepted, to many parts of our own island. Such an establishment as I have in prospeet would require a very large capital. But how can capital be expended more serviceably to the human kind than for the Institution proposed. The large sums now embarked, undoubtedly for improvements in the eondition of human life, do not concern men, however, so nearly as the immediate preservation of life, and palliation of disease, above all pulmonary consumptive cases, yet the expectation of pecuniary gain induces persons to beeome adventurers. On a due estimate of the advantages of sueh an undertaking to the subjects of the United Kingdom, there seems no reasonable doubt that in the present redundanee of capital the speculator would be repaid by ample interest. At least sueh an undertaking is one of greater promise

than many others, or perhaps more so than any now in progress or in contemplation.

I am, dear Sir, with best wishes,

Yours faithfully,

GEORGE PEARSON.

George Street, Hanover Square,
October 18, 1824.

DESCRIPTION

OF THE

PLATES.

PLATE I.

The figures in this Plate exhibit the plan and section of a spherical boiler for generating steam. *Fig.* 1 shews the plan of the fire-place and flue under the boiler, (see art. 97, where the proportions are given,) A the door to the fire-place, B the place for the fire. The dotted line and arrows shew the course of the flame and smoke, which go into the chimney after passing the damper, D. A double wall surrounds the fire-place, in order to prevent the escape of heat, and it also renders a less quantity of fuel necessary to heat the boiler when first set to work. *Fig.* 2 is a section of the boiler and fire-place, supposed to be made through from A to C. The door to the fire-place is shewn at A, the fire at B, and the ash-pit at E should be as deep as the nature of the situation will allow of, with the aperture to it at F not larger than the proportion assigned in art. 91. The object is to give velocity to the air passing through the burning fuel. The throat of the fire-place at K should not exceed 3 inches in depth. In this section, the double walls and cavities for reducing the escape of heat, are shewn; and the boiler itself is supposed to be inclosed by a thin case of metal, with the interstice between it and the boiler filled with pounded charcoal. (See art. 49, where the loss of heat from a naked boiler is shewn.) G, G, are guage-cocks; when the boiler is in proper trim, one of these should let out steam and the other water. M is the man-hole, or place to open for cleaning out the boiler. S the steam-pipe, which should be cased to prevent loss of heat; the size of this pipe may be determined by the rule in art. 127. W is the pipe for supplying the boiler with water; H a wire, by which the stone-float on the surface of the water moves a cock in the pipe, W, to admit a fresh supply of water when necessary. The float should be thin, and of sufficient area to render its action certain. O is a small pipe for admitting air to the boiler in the case of a vacuum being formed, or to allow steam to escape if it become too strong; it should be proportioned by the rule, art. 103; and it will be an advantage to make it a distinct pipe, instead of joining it with the feed-pipe. The space, U, between the door and the fire, should be kept filled with fuel: that which is in should be pushed forward into the fire-place as the former charge burns away, and the space refilled, so as only just to allow the door to close. By this means, any gas which distils from the fresh fuel, having to pass over the red-hot embers through which the air from the ash-pit ascends, will be inflamed. For further information, see Chap. V.

Fig. 2.

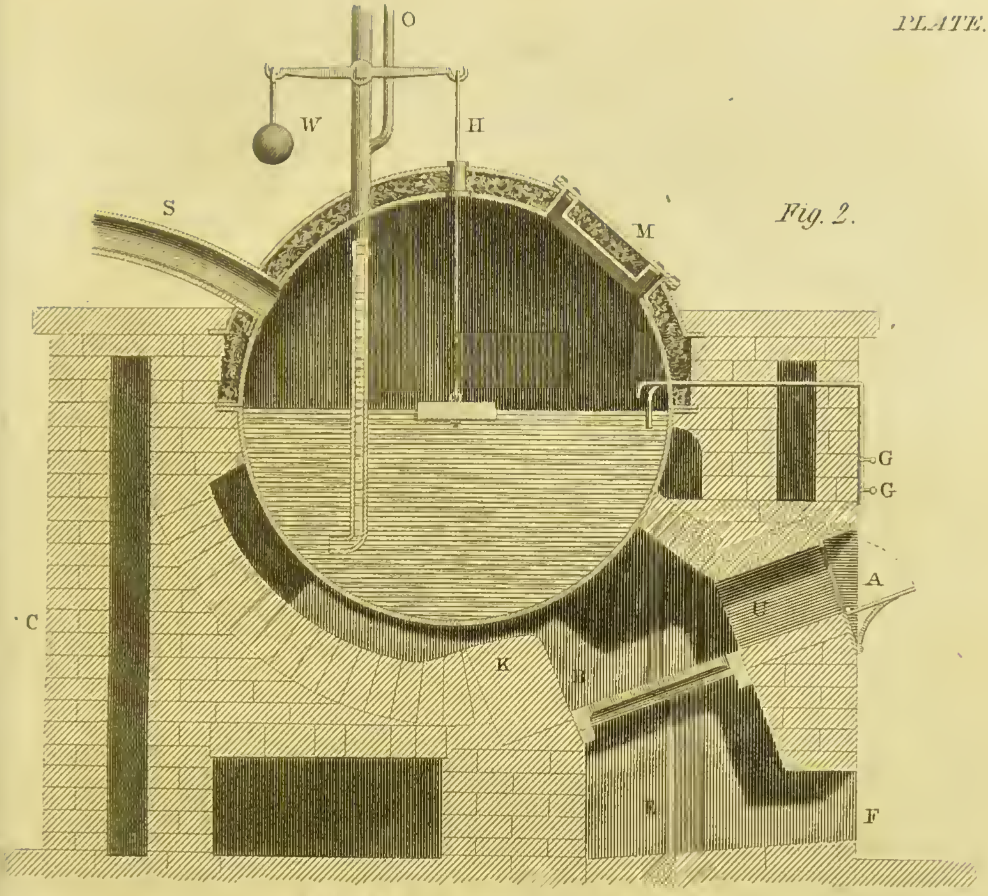
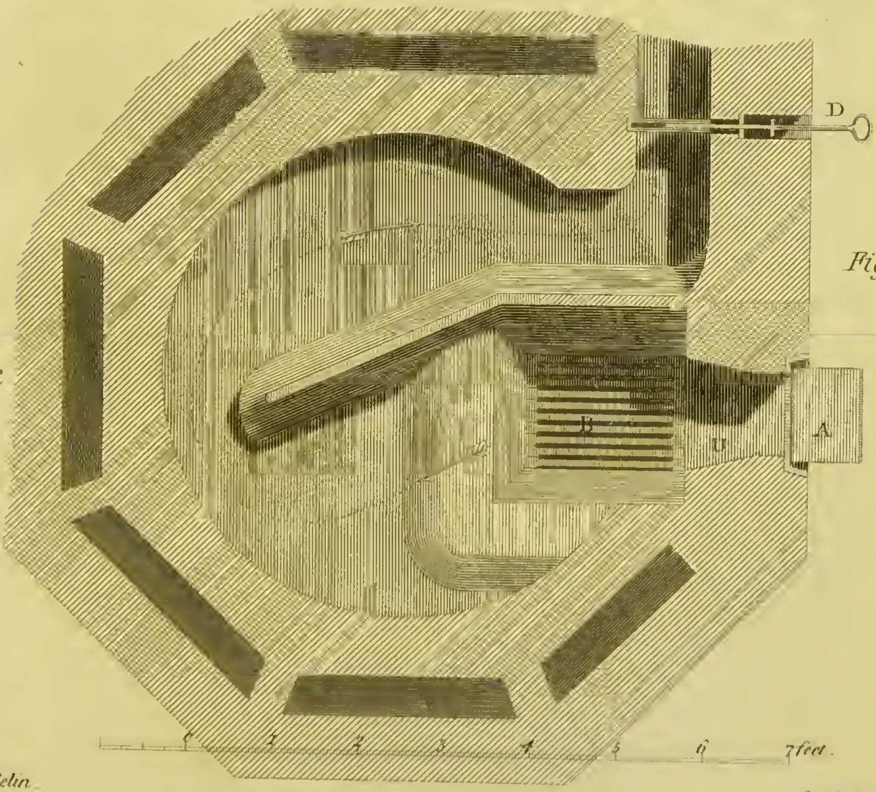


Fig. 1.



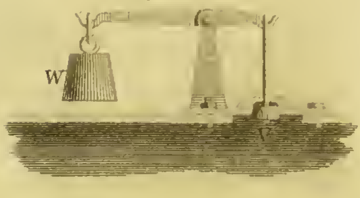
T. delin.

G. Gladwin sculp.

London, Published Mar 1, 1824, by J. Taylor, 59, High Holborn.

Fig. 6.

Fig. 5.



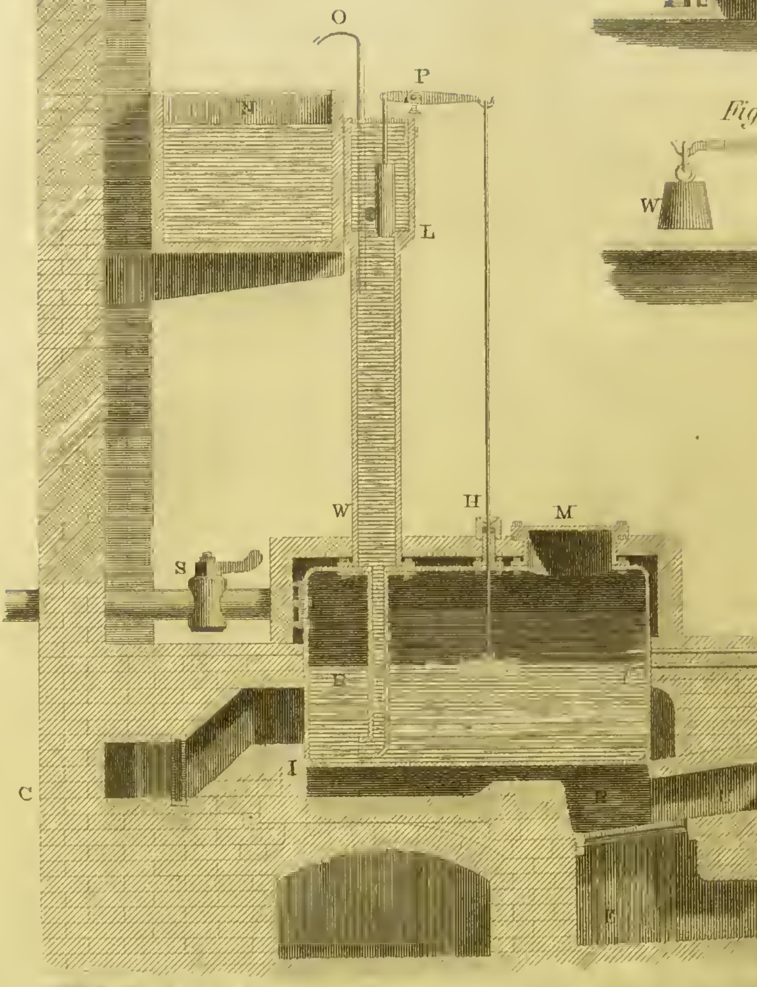


Fig. 4.

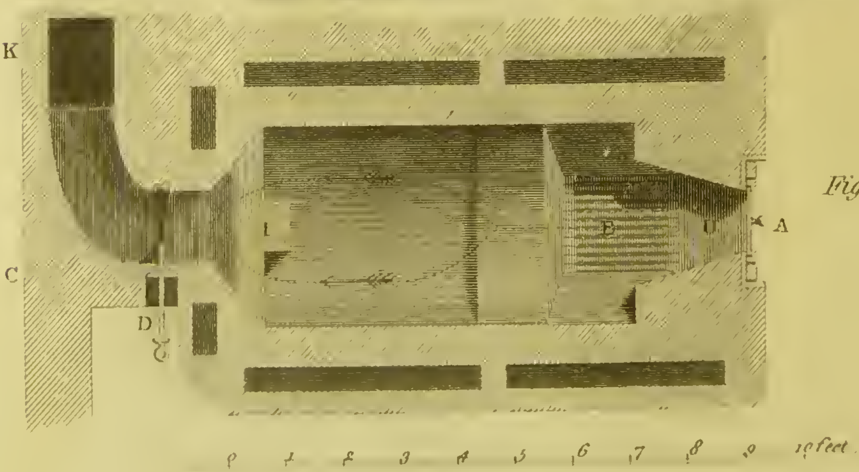


Fig. 3.

T. T. delin. *G. Gladwin sculp.*

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PLATE II.

The figures 3 and 4 of this Plate, shew the plan and longitudinal section of a Cylindrical Boiler, with its fire-place and apparatus. *Fig.* 3 represents the plan of the fire-place and flue under the boiler; for the proportions, see art. 97. B is the place for the fire, from whence the flame and smoke pass as shewn by the dotted lines and arrows, and after being divided by the brick, I, they pass through the damper, D, into the chimney, K. The fire-place is inclosed by double walls, to prevent the escape of heat. See art. 134. *Fig.* 4 represents a section from A to C, through the boiler and its fire-place; A is a sliding plate, which closes the opening for supplying fuel to the fire. B is the fire-place, E the ash-pit, L W the apparatus for supplying water to the boiler, N the cistern, H the wire by which the stone-float on the surface of the water in the boiler moves the valve in the cistern head at L, to admit a fresh supply of water when that in the boiler descends. O is a small open pipe taken up a little above the cistern, which will admit air to the boiler if a vacuum should be formed in it, or allow water and steam to escape whenever the pressure becomes greater than equivalent to a column of water of the same height as the cistern. See art. 103. S is the steam-pipe, with a stop-cock to let steam into the pipes, or shut it off, as occasion may require; the rule for its area is given at art. 127. M is the man-hole for cleaning out the boiler at. G, G, are the guage-cocks, to ascertain the state of the boiler in respect to water. This boiler is supposed to be cased with brick-work, to prevent the escape of heat from its surface, with either a hollow cavity between the brick arch and the boiler, or a stratum of slow-conducting matter. For further illustration see Chap. V.

Fig. 5 is to explain the principle of the internal safety-valve. See art. 102.

Fig. 6 shews a mode of covering the man-hole, so that it may be readily opened, and also answer as a means of safety if the pressure of the steam should be likely to endanger the boiler or apparatus. See art. 107.

PLATE III.

The figures 7 and 8 shew the most simple and effective Method of joining Steam-pipes. The joint is held together by the screw-bolts *a*, *a*, *a*, *a*. See art. 124 and 125.

Fig. 9 is an inverted syphon, through which the water passes as it is produced by the condensation of the steam in the pipes, and runs off into a drain by a continuation of the pipe, C. To let the air out of the pipes, when the steam is let in, there is a small pipe and stop-cock, E, which may be made self-acting by fixing a lever handle to the stop-cock, and a connecting rod from the lever to an eye fixed in the wall. By this simple addition, the cock will always be open when the pipes are cold, and gradually close as they become of the temperature of the steam. See art. 130, where a rule for the diameter of the waste pipe is given.

Fig. 10 is a steam-trap, for the condensed steam to escape as it condenses. When water accumulates in the box, it floats the hollow copper cylinder, D, and runs away through the pipe, F, into a drain, the stop-cock and pipe at S being added for letting out the air; and may be made self-acting, as described above. See art. 131. In this trap there is sufficient space in the box to allow the water to separate from the air; when this is not the case, both water and air will often issue from the air-pipe in letting in the steam.

Fig. 11 shews a means of applying the force of the steam in the pipes for raising the condensed steam to a higher level. The valve, C, should be rendered nearly as light as the same bulk of water. It may be useful in some instances where there is not sufficient drainage for applying the preceding methods. See art. 132.

Fig. 12 is a perspective sketch of a side-table, of marble or stone, to contain a mass of pipes in a hall, a staircase, or a gallery. The open brass-work is to admit air to the pipes to be heated, and to allow it to return to the room. The form and disposition of things of this kind may be infinitely varied; the figure will perhaps be sufficient to illustrate the principle alluded to in art. 119 and 135. In every contrivance for heating air, the immediate rise of the hot air in a vertical jet should be avoided; its motion should be either horizontal or inclined downwards, so as to diffuse it as much as possible.

PLATE. III.

Fig. 8.

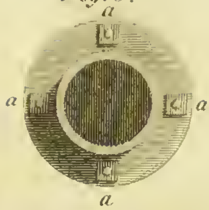


Fig. 7.

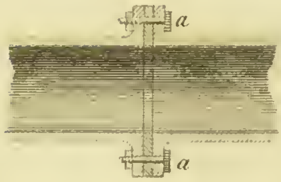


Fig. 9.

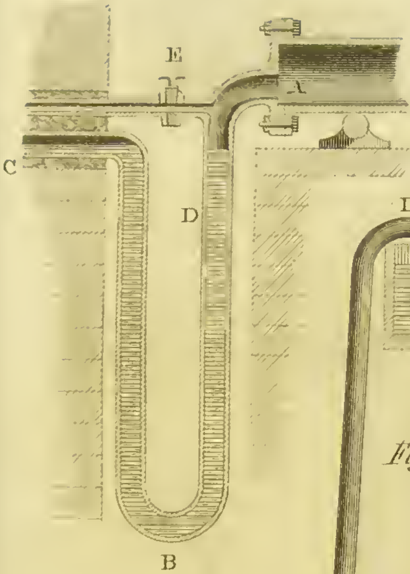


Fig. 11.

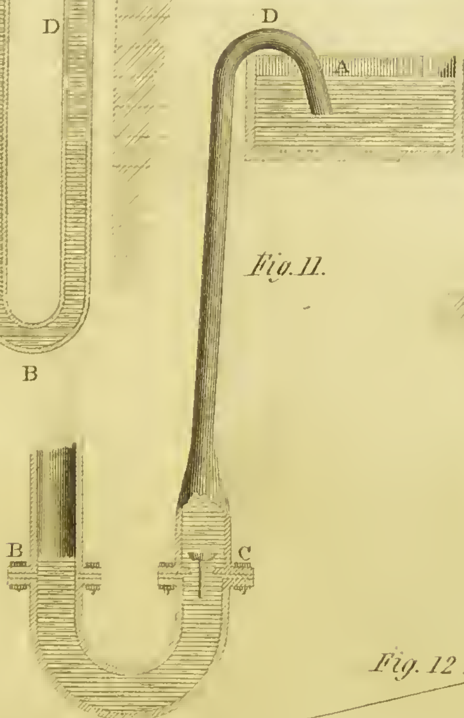


Fig. 10.

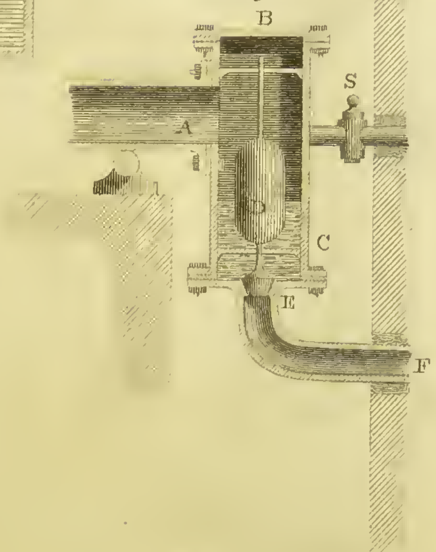
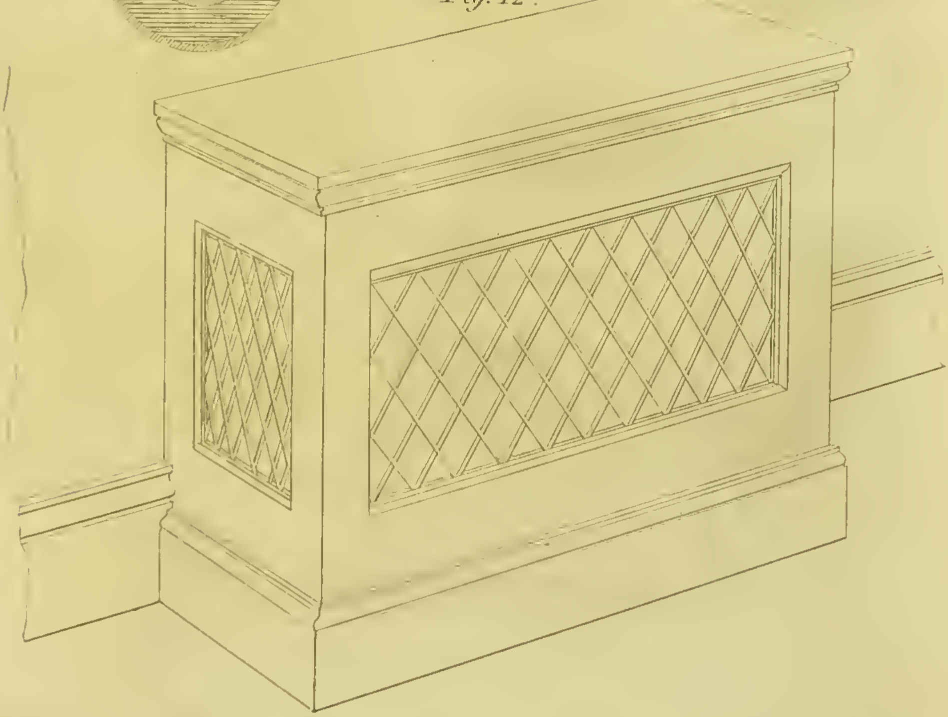


Fig. 12.



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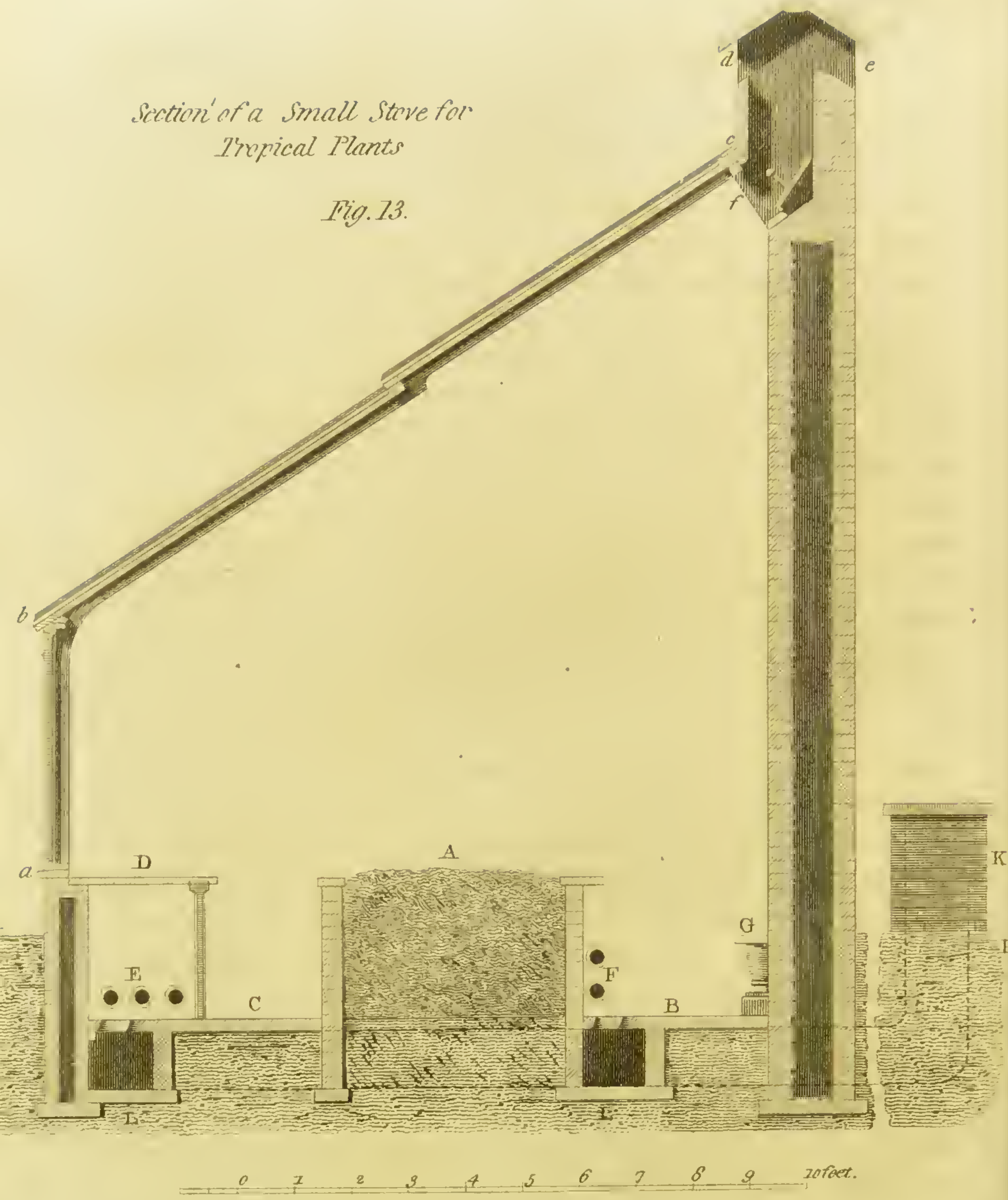
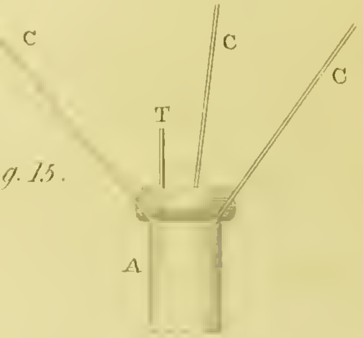
Section of a Small Stove for Tropical Plants

Fig. 13.





g. 15.

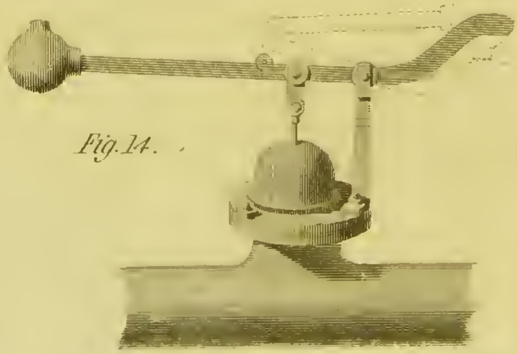


Fig. 14.

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PLATE IV.

The principal figure in this Plate, *Fig*. 13, is a section of a Stove for Tropical Plants. The front, *a b*, is supposed to be glazed in squares, the frames of the sashes of wood, with light copper bars. The roof, *c b*, to have wooden lights sustained by iron rafters, made light so as to intercept as little of the sun's rays as possible.* The back and front walls are supposed to be built hollow, in order to prevent the escape of heat in winter. In the middle of the stove a bark bed, A, for the reception of large plants in pots, continues the whole length, excepting spaces for passage at each end. C is the front path, and B the path along the back, D a stone bench for smaller plants in pots. G larger pots in recesses for plants to train against the back wall, F two steam-pipes at the back of the bark bed, E three pipes for steam along the front. The ventilation is supposed to be carried on by air conduits for admitting cool air: the air enters at K, and passes under the paving in the conduits, L, L, and is let into all parts of the house at the same time, through small holes in the paving which covers the conduits, so as to ventilate the stove in a very uniform manner, and the quantity regulated by a sliding plate. The place, K, where the air enters, is broken off, to shew that it may be at any distance from the house; but it should be in a shady situation, and sheltered from winds. The hot air in summer is supposed to pass out at the ventilators, *f*; which may be opened and shut with a stick having a hook on its end. The air to go out at *e* or *d* under the coping. The lights of the roof and front are supposed to be all fixed, and made as close as possible. The ends to be glazed, and all the sashes made to open; every part which is so made to open being made to shut air-tight.

Fig. 14 is a representation of Messrs. Loddiges' copper valve for steaming forcing-houses and stoves. They are fixed on the pipes, and when the ball is turned over, as indicated by the dotted lines, the whole bore of the pipe is opened, and the house is filled with vapour in an instant, producing a fine dew on the plants, and elevating the temperature.

Fig. 15 shews the mode I adopted for suspending the cylinders of hot water, in order to ascertain the rate of cooling from different surfaces; *C*, *C*, *C*, were threads of slightly twisted cotton, attached to three points in a plane at a considerable height above the cylinder, and which are not shewn. T is the stem of the thermometer, the bulb being within the cylinder, and near the interior surface, as shewn by the dotted lines at A. See art. 42.

* Roofs of wrought iron admit most light, with a loss of heat only about in proportion to the increased area of glass.

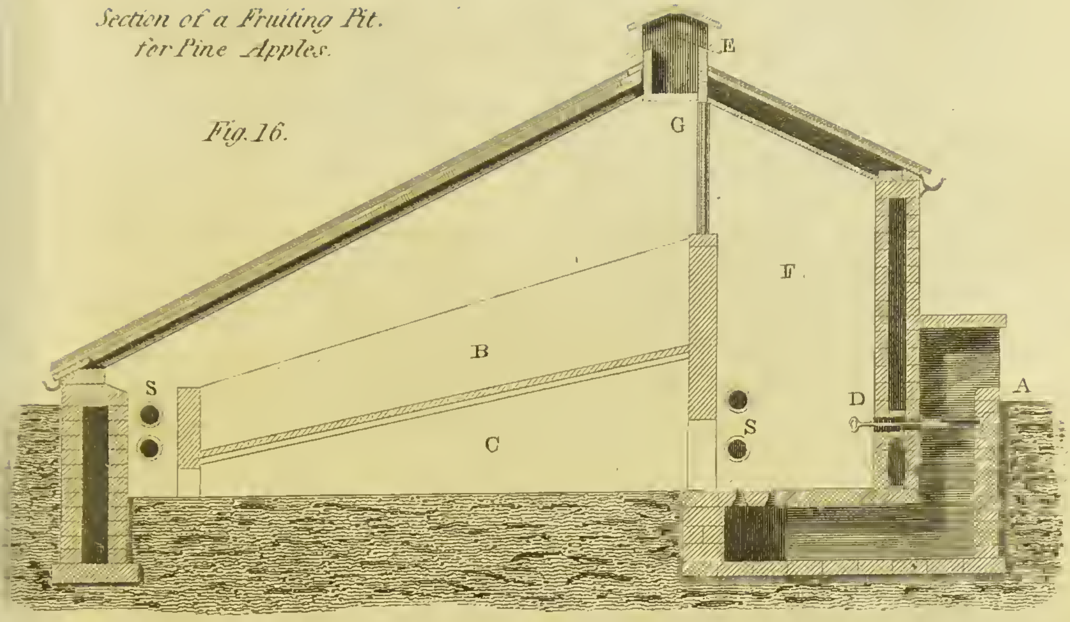
PLATE V.

Fig. 16 represents a section of a Pit for fruiting Pine-apple Plants, where B is the bed to contain the tan or other matter used to plunge the pots in, which may have a bottom of flag stones, slates or tiles, so as to leave a space, C, below it; or it may be entirely filled in the ordinary manner, so as not to leave a space below. The space, F, along at the back, is for a footpath; and as light to this part will not materially benefit the plants, while the glass will take away much heat, it is proposed to be close boarded and slated, and also ceiled, so as to leave a hollow cavity, and render the escape of heat nearly insensible. The front and back walls are made double for the same reason. The steam-pipes, S, S, are placed along the front and the back of the bed, so as to afford a uniform heat; but where only three pipes are required, it would be best to put two at the front. To produce a more effective ventilation in summer, an air conduit is made under the path; the cold air enters at A, and the quantity is regulated by the slider, D. The hot air goes out at E; this outlet should be made to close very accurately, it is shewn closed by the dotted lines; and in the winter season, all of the outlets should be closed with boards, as shewn by the dotted lines at G, except one or two. The free circulation of air will be greatly improved by the open space, C. See art. 159—161, where the construction and proportions are given more in detail.

Fig. 17 is a section of a peach-house, where the trees, A, A, are intended to be trained upon trellis upon the inclined walls, B, B. These walls are constructed with hollow spaces, both to save material and to prevent loss of heat. The steam-pipes, S, S, are placed so that the air, as it is warmed, may ascend over the surface of the trees. And the air enters the conduit at the back at C, and passes into the lower cavity of the back wall, as shewn by the dotted lines; this conduit must have a slider to regulate the admission of air; the air as it enters the house is intended to play against the steam-pipe at the back, so that in the time of forcing, a small change of air may be given at the back wall, which will be warmed as it enters. D is supposed to be a shed behind the house, which may be wider or narrower as convenient. F, F, are trellis footpaths; E, the ventilator at the top, for heated air to go out in summer; it may be pushed open or drawn close by a rod with a hook. The principles of construction and proportions, are given in art. 165—167.

Section of a Fruiting Pit for Pine Apples.

Fig. 16.



Section of a House for Forcing Peaches.

Fig. 17.

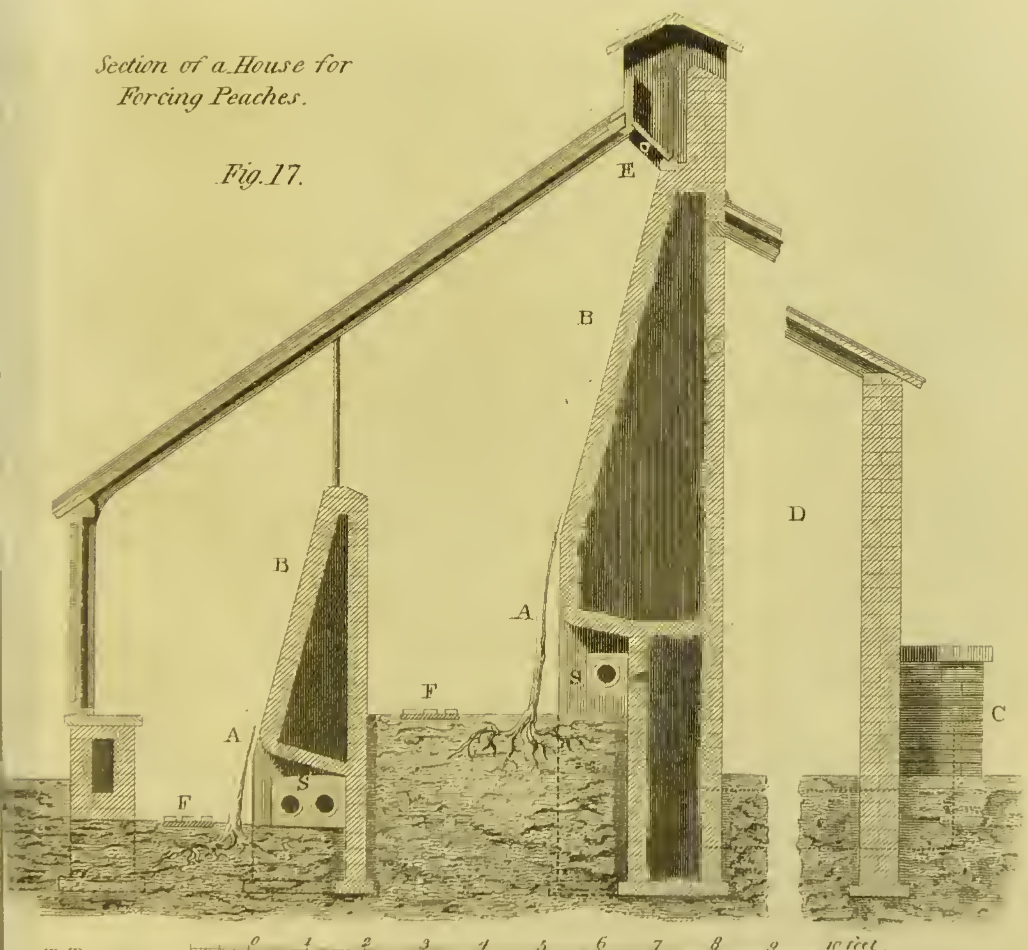


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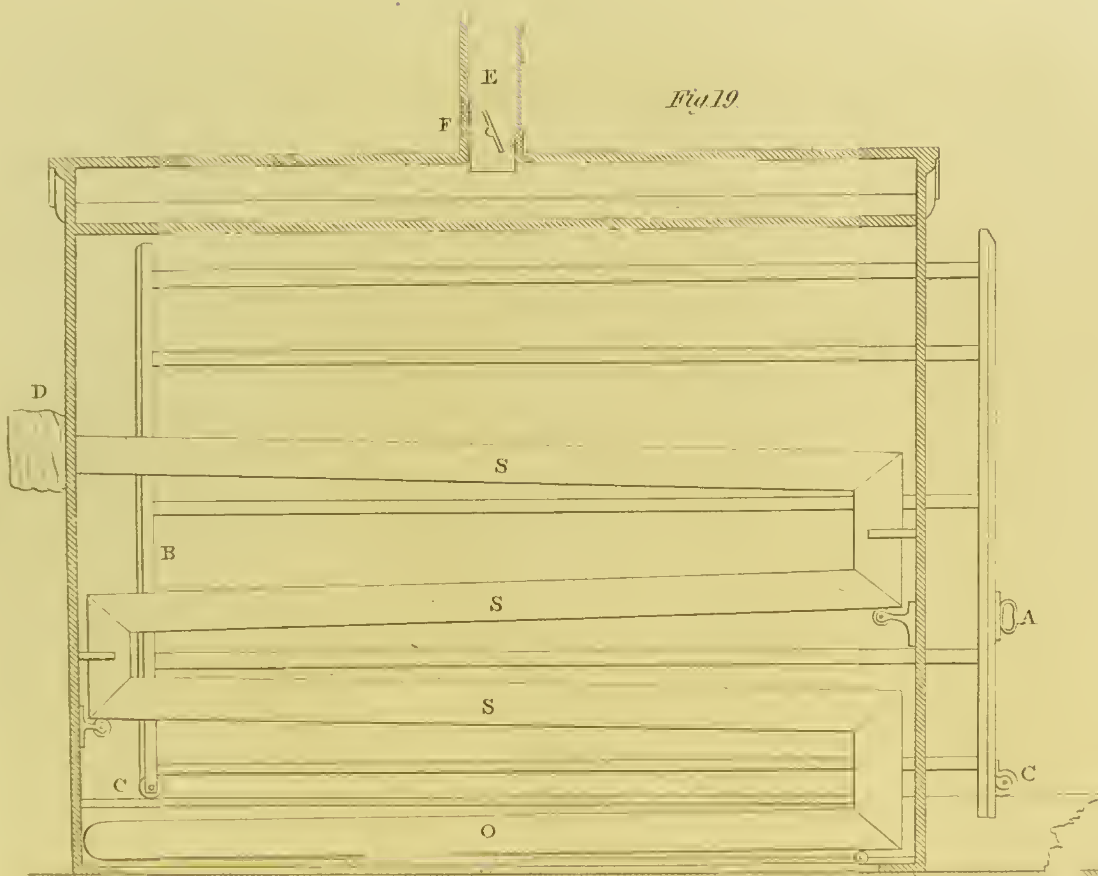
Fig. 19.



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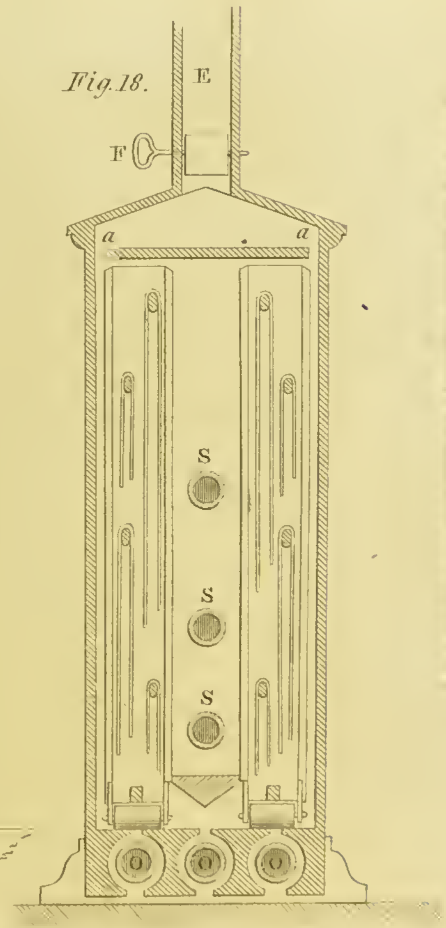

Fig. 20.

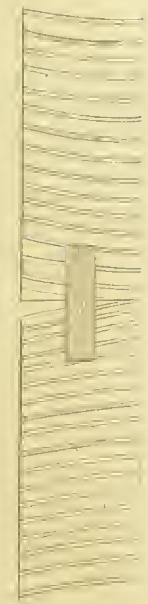

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PLATE VI.

Fig. 18 represents the cross section, and *Fig.* 19 the longitudinal section, of a Family Drying-closet for a Laundry, to contain two horses. One of the horses in *Fig.* 19 is represented partly drawn out; when the articles are to be taken off and fresh ones put on, it is drawn out by the handle, A, till the other end, B, stops the aperture into the closet; it moves on the rollers, C, C. The steam-pipe is introduced at D, and passes to and fro, as shewn by S, S, S; and then under the bottom, as at O, O, O, so as to heat the air before it enters the closet. The air is admitted at the bottom, and warmed in passing round the pipes, O, O, O, *Fig.* 18; and when it has become charged with moisture from the wet articles, it ascends through the narrow spaces, *a*, *a*, and finally passes out at the funnel, E. The outlets, *a*, *a*, continue along the whole length, and are narrowest in the middle, and wider towards the ends. The quantity of air passing through is regulated by the valve, F. To sustain the temperature of the air, and of the articles that are drying, the steam-pipes, S, S, S, are necessary. The steam-pipes should rest at one or both ends on rollers in brackets. If there be no heat wanted in the laundry, the pipe may be covered, as shewn at D.

All light articles will require to be secured to the rails of the horses; but the draft can be regulated at pleasure by turning the valve, F.

The great advantage of this plan, consists in confining the heat entirely to the substances to be dried; and consequently saving fuel; in keeping the laundry free from damp air, and oppressive heat; and in rendering less space necessary. The principles and proportions are fully explained in Chap. XI. this particular case, in art. 199.

Fig. 20. The wood for forming the external case of the drying closet, should be cut into narrow strips, not exceeding four inches wide, and joined as shewn in this figure. When the wood can be selected so that the annual rings are nearly perpendicular to the surface of the wood, as shewn in the figure, it will be found to warp less; as I have shewn in the art. "Joinery," Napier's Supplement to the Ency. Brit. Vol. V. p. 84.

PLATE VII.

Fig. 21, is a plan of Portland Chapel, Cheltenham; and *Fig.* 22, 23, and 24, are sections to shew the arrangement adopted for heating it by steam. The chapel is 62 feet long, 25 feet 8 inches wide, and 26 feet high. The boiler, containing 24 cubic feet, is fixed underneath the chapel, in a room adjoining the school-room, from whence a main steam-pipe *m* (*Fig.* 23) conveys the steam to a row of pipes, S, S, on each side of the chapel. These pipes are near to the walls and the floor, passing through the ends of the seats, and affording to each pew an agreeable warmth. They communicate with two pedestals, *b*, *b*, at the foot of the gallery stairs, near the entrance to the chapel. Also a large pedestal, heated by steam, is placed in the table pew under the pulpit at P; and being made double, it warms a quantity of fresh air in its passage through it, which is admitted for the purpose of ventilation. The fire is generally lighted under the boiler late on Saturday night, and allowed to burn slowly all night; in the morning, about eight or nine o'clock, it is made up, and the steam let into the pipes, which renders the chapel warm and comfortable before the congregation assemble; when the steam is shut off, and the fire suffered to go down; but is made up again, and the steam passed through the pipes, previous to the congregation assembling in the evening. The steam apparatus was erected by Messrs. Bailey, of High Holborn, in 1821.

The application and proportions for churches and chapels, is illustrated in Chapter VII. art. 137. When churches and the like are warmed by hot-air stoves, all the heated air ascends to the ceiling, and consequently is never effective in warming the pews; but by small steam-pipes a certain portion of heat can be given to each pew, so as to warm the air and wood-work, and render the whole comfortable without heating the air too much. There is nothing more injurious, than to be in a place where every thing is cold except the air in it; for all other bodies abstract heat more rapidly than air; and consequently feel chilly and disagreeable. The trouble of lighting a fire a little sooner the night before would be more than compensated by the advantage of airing the chapel; the steam should be let into the pipes at night, for it is of more importance to clear the place of damp air than to give much heat while the congregation is assembled.

PLATE VII.

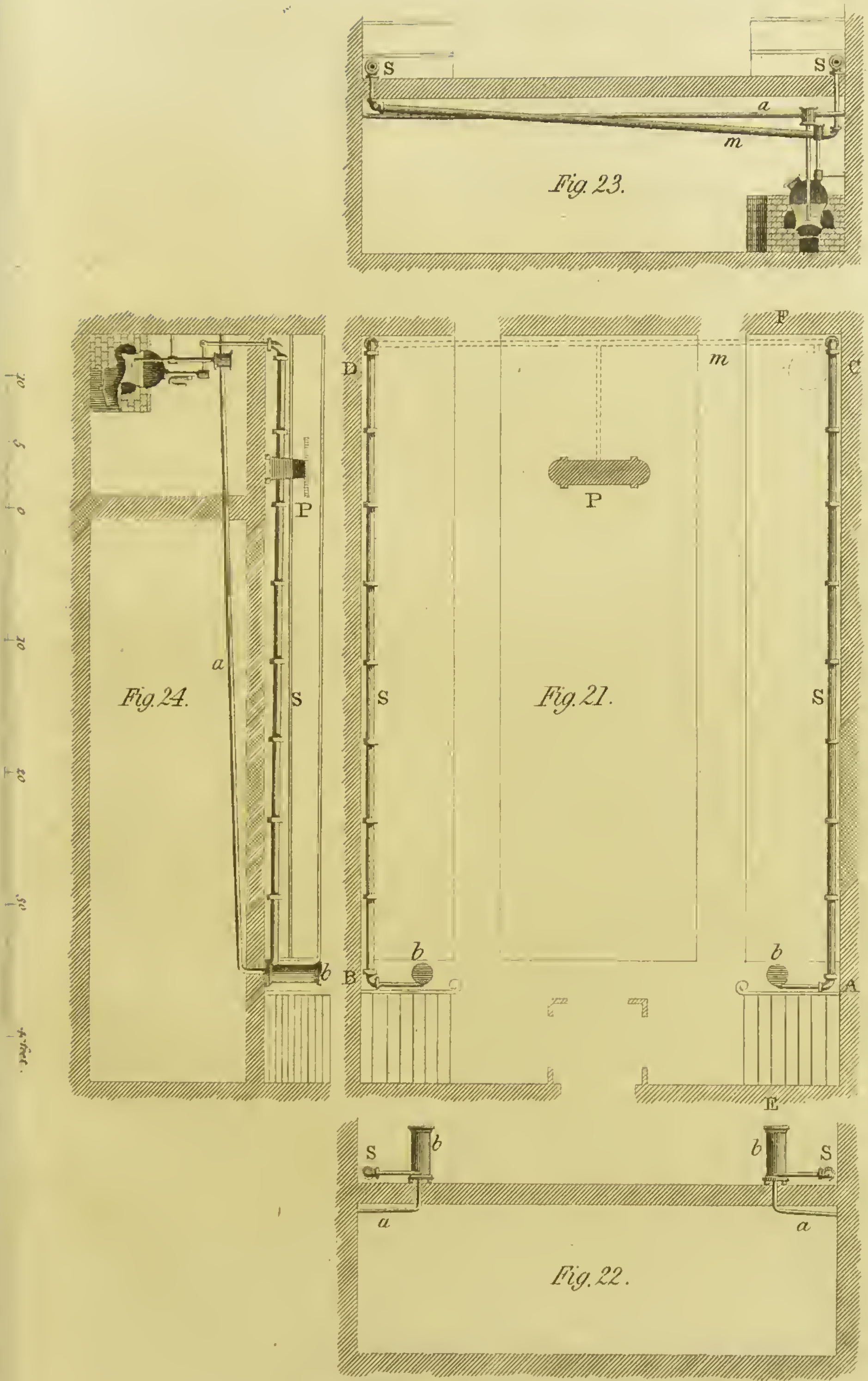

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PLATE. VIII.

Fig. 26.

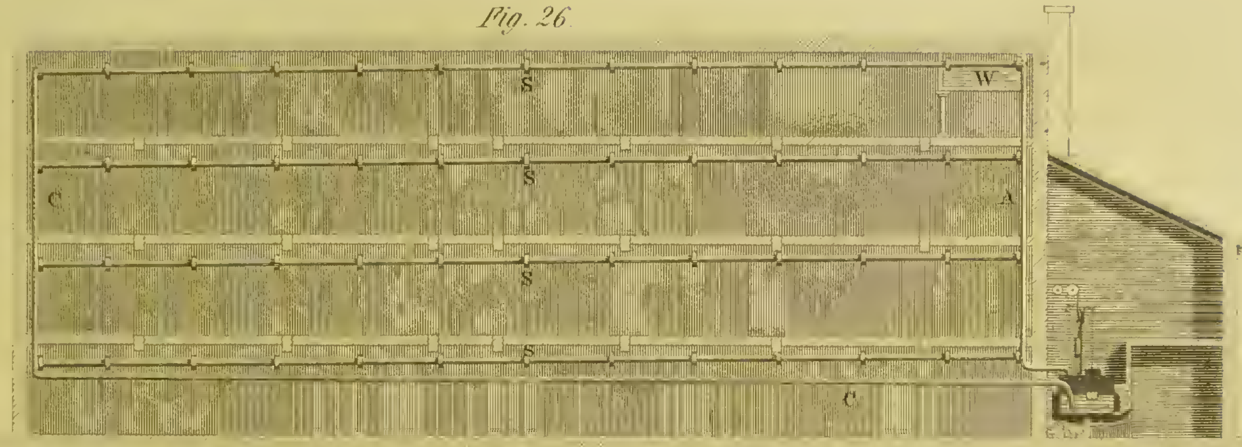

Fig. 25.

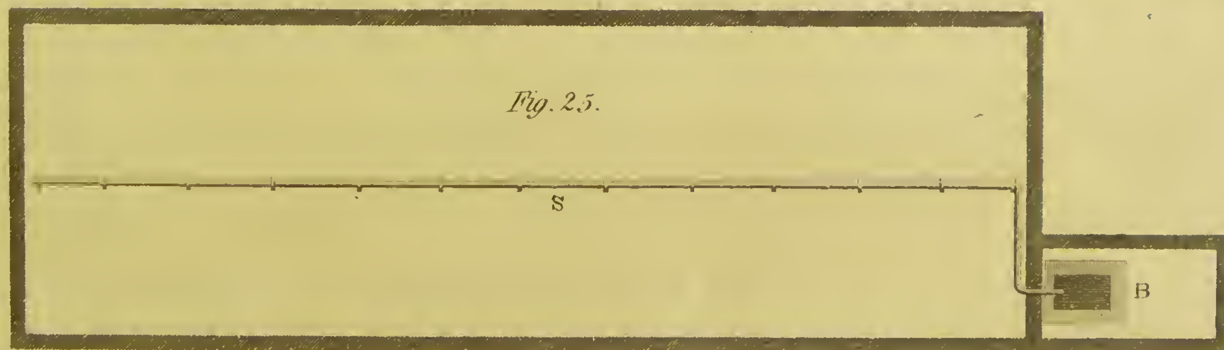

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PLATE VIII.

Fig. 25 is the plan, and *Fig.* 26 a longitudinal section of a Silk Mill, belonging to Messrs. Shute and Co. of London, and situated at Watford, Herts. This mill was formerly heated by thirteen iron stoves, with pipes for the smoke passing out at the windows, and through the roof. But in 1817, the proprietors had the stoves removed, and the steam-apparatus put up by Messrs. Bailey, of Holborn, which has been in constant use since that time, without requiring the least repair B is a wrought-iron boiler, cubic contents 38 feet, placed in a shed erected for the purpose, and the chimney is carried up on the outside of the mill. The main steam-pipe, A, leads from the boiler to the ceiling of the upper story of the mill; and from this pipe there is at each floor, a branch-pipe of cast iron, S, the whole length of the mill, suspended from the ceiling in consequence of the mill being full of machinery; each branch-pipe has a valve to regulate the supply of steam, and a syphon at the opposite end. C is a small pipe for returning the water of condensation to the boiler from the upper three floors; that collected from the steam-pipe of the lower floor, is used for washing and other purposes. The power of making a good arrangement was in this case extremely limited, the mill being already built and full of machinery. But the advantages of this one are great. 1st. A considerable reduction of the rate of insurance. 2ndly. The absence of all smoke, soot, dust, and ashes, which had been found very injurious to the silk under the former plan. 3rdly. A saving of fuel, and also of labour in attending the fires. 4thly. An equable heat, instead of the partial one of the stoves, and a regular supply of fresh air into the mill warmed by the main-pipe, A. 5thly. The labour proceeds without interruption, and in a comfortable temperature. 6thly. The children are free from chaps and chilbains in the winter season, which may be in some measure owing to their having warm distilled water to wash their hands. The mill is 106 feet four inches, by 33 feet; the upper story, eight feet high, is warmed by a pipe of three inches diameter; the next story, eight feet eight inches high, by a pipe of four inches; the next, nine feet high, by a pipe of four inches; and the lower story, nine feet high, by a pipe of five inches diameter. The building is supplied with water from a cistern at W. See art. 141.

PLATE IX.

This Plate shews the plan of a Steam Apparatus in the gardens of a gentleman in the neighbourhood of London;* and is an example of its application to warm distant and unconnected Forcing-houses, Conservatories, &c.

There are two boilers fixed in the kitchen garden at N, remote from the dwelling-house, and which have each a communication with the main pipes with stop cocks, so that either or both of the boilers may be in use at the same time.

The dimensions of the houses which are heated are,

A, the Conservatory, adjoining the dwelling-house,		67 feet by 17.
B, the Green-house		48 feet by 17.
C, and D, two Graperies, each of them		30 feet by 18 feet 8 in.
E, and F, two Pine Pits,	Succession Pit	33 feet 4 in. by 13 feet.
	Fruiting Pit	33 ft. 5 in. by 13 ft. 6 in.
G, an early Grapery		17 feet by 17 feet.
H, a Stove for Plants		17 feet by 17 feet.
I, a Peach-house		60 feet by 10 feet.
K, a Strawberry Pit		59 feet by 4 feet.

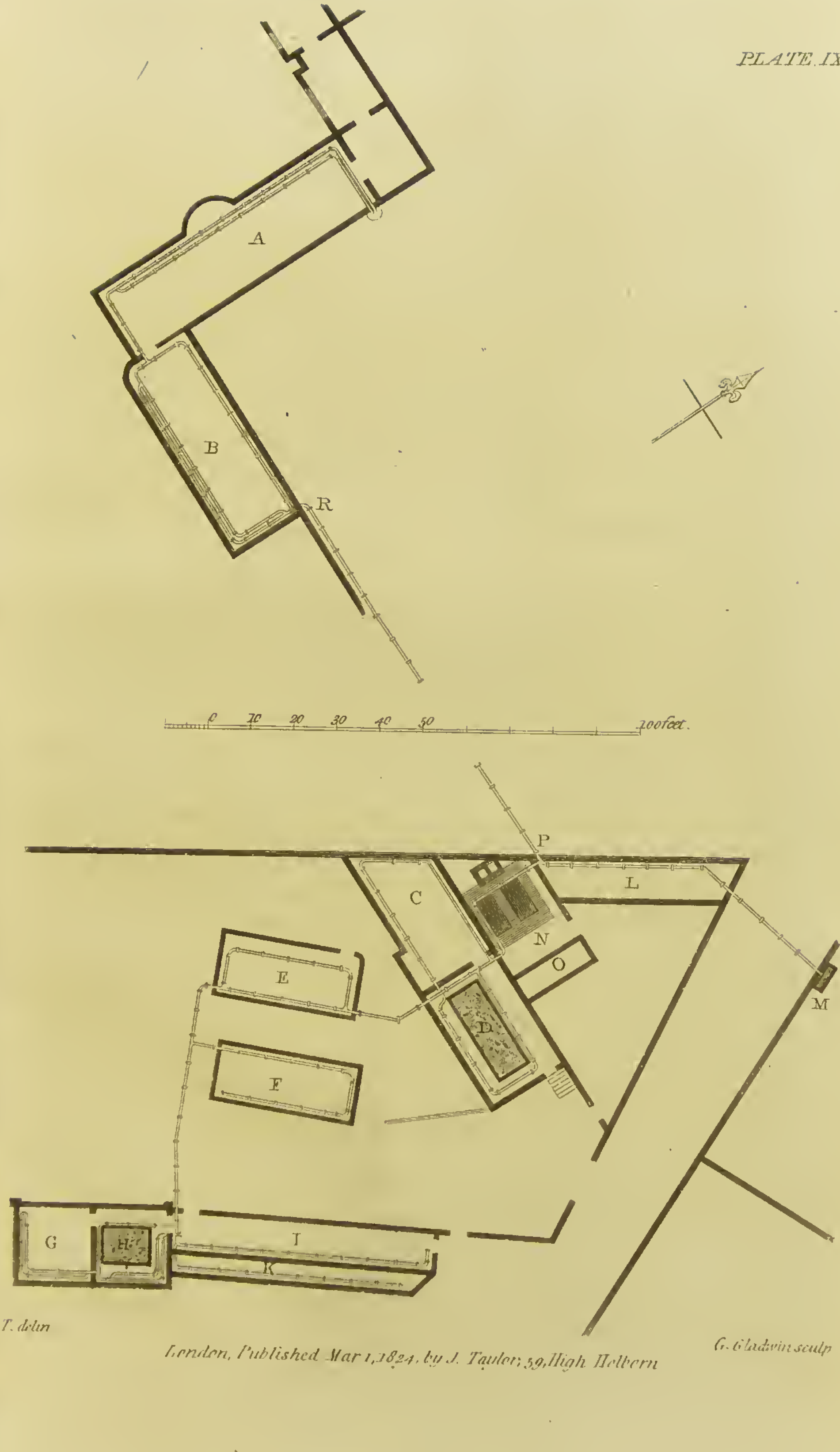
L, a Mushroom Shed; and M, a Potatoe Steamer in the farm yard.

This steam apparatus was erected in 1821, by Messrs. Bailey, of 272, High Holborn.

The heat is transmitted so equably, that there is not two degrees of difference indicated by a thermometer whether placed against the pipe near the boiler, or against it at 550 feet distance from the boiler. The whole length of the main-pipe, P R, is not shewn by the plan, because there was not space on the plate; and the pipes are shewn larger than their true proportion to render them distinct; and therefore do not render the saving of space so evident as it is in the houses themselves; while the plants are free from the smoke and dust, as well as the loss and inconvenience which attend the cracking and bursting of flues. The houses are steamed with the greatest ease, and a considerable establishment is managed by attending only to one fire. See art. 10—12, and Chap. IX.

* In consequence of omitting to reverse the drawing for the engraver, the plate shews the houses with a west aspect instead of an east one.

PLATE IX.



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